Enhancement of Three-Body Wear Resistance of Steel Substrate using Molybdenum Coating for Steel Roller Conveyor

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Keywords: Wear, Resistance, Steel, Molybdenum Coating.

Abstract: The main focus of this work is enhancing the steel rollers wear resistance which is used in mining industry conveyor systems. Wear and efficiency of steel conveyor system is affected by the presence of sand, dust and grit (abrasive particles) and by the continuous contact between metal surface with steel roller. To overcome the above issue, application of molybdenum powder coating for the steel is suggested using plasma thermal spray coating. As per the ASTM (American Society for Testing and Materials) standards the experiments are conducted and the performance enhancement analyzed for the coated samples by comparing with uncoated samples. ASTM G65 is a test method developed by ASTM International to evaluate the abrasive wear resistance of materials using a dry sand/rubber wheel abrasion test. This test method is commonly used to assess the durability and wear performance of various materials, coatings, and surface treatments. SEM (Scanning Electron Microscope), EDAX (Energy Dispersive X-Ray analysis) and hardness tests are performed to measure the wear resistance and wear surface properties. It is proven that the molybdenum coating plays very important role in improving the three-body wear resistance of steel conveyor rollers. SEM analysis confirmed a smooth and well-adhered coating, while EDAX revealed the presence of molybdenum on the coated surface. Hardness tests indicates a notable increase in hardness, further supporting the enhanced wear resistance. This research highlights the potential of molybdenum powder coatings to enhance the durability and lifespan of steel rollers in conveyor systems operating in harsh environments. The findings contribute to the development of effective strategies for reducing wear and optimizing the performance of mining and construction equipment.

1 INTRODUCTION

Abrasive wear is observed in manufacturing, transportation, mining and construction industries, also in day-to-day life. It has very significant effect on the life span and efficiency of the components or parts subjected to abrasive wear. It may lead to material loss, decrease in dimensional accuracy, higher surface roughness and reduction in efficiency. In industries it may occurs in parts or components exposed to harsh environments such as grinding tools, engine components, conveyor belts and also in cutting machinery. To overcome the above issue, application of molybdenum powder coating for the steel is suggested using plasma thermal spray coating. C S Ramesh (2018) et.al highlighted the effect of molybdenum and molybdenum silicon carbide coatings on mild steel to improve the wear resistance, to improve the tribological properties and also to reduce the friction. High-velocity oxy-fuel (HVOF) technique is used for the coating to achieve less porosity, higher coating density and good bonding with the material and microstructure, composition, phase change and mechanical properties are evaluated using microhardness testing, EDX, XRD, and SEM. The tests were conducted as per ASTM standards and the improved wear resistance and reduction in friction are demonstrated by the ASTM G65 abrasion tests (C.S. , et al. 2018).

Patel G C (2022) et.al studied the wear loss and microhardness of Mo-Ni-Cr coated super duplex stainless steel to optimize and analyze the plasma spray parameters effect on experimentation. The parameters such as current, voltage, spray distance

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M., A. and N., V.
Enhancement of Three-Body Wear Resistance of Steel Substrate Using Molybdenum Coating for Steel Roller Conveyor.
DOI: 10.5220/0012525700003808

In *Proceedings of the 1st International Conference on Intelligent and Sustainable Power and Energy Systems (ISPES 2023)*, pages 116-124
ISBN: 978-989-758-689-7

and powder feed rate are influencing factors to achieve required coating properties. The wear behavior, hardness and microstructure were evaluated using wear testing, microhardness testing and surface roughness analysis. It is discovered that proper optimization of plasma spray variables on microhardness and wear loss is needed to achieve the better quality and performance of coatings. Han. Ya-guang (2017) et.al focused on the correlation between wear resistance and micro structural properties of molybdenum coatings on different substrates using APS (Atmospheric Plasma Spraying). The authors discussed the importance of process parameters of plasma spray coating such as gas flow rate, powder flow rate and spray distance in controlling properties and microstructure of coatings using EDX, SEM and microhardness testing.

Cristian Puscasu et.al investigated the thermal spray molybdenum coating properties to increase the durability and enhance the wear resistance of railway axles. It is proved that wear related damages are reduced, performance of axles are improved and service life is also extended using molybdenum coatings. The main challenges of railway axles such as cyclic loading, harsh operating conditions and high loads are handled using protective coatings using molybdenum. This study discussed the coating properties such as microstructure, mechanical strength, hardness and adhesion and also their significant importance on performance of railway axle applications. H Adarsha (2018) et.al highlighted the influence of HVOF(High-Velocity Oxy-Fuel) technique on manufacturing well-bonded and dense coatings with better mechanical properties such as less friction coefficient, higher hardness value and better adhesion to the substrate material(SS304 and A36). These materials are mainly used in the mining and construction industries under abrasive environment, which required the wear enhancement and extended life span. Huang Long (2018) et.al studied the wear resistance comparison of the steel with and without (Ti,Mo)C particles. This study explores the influence of parameters such as concentration, particle size and distribution of particles on the improvement of wear resistance performance and also characterization of materials is performed using harness testing, SEM and EDX to analyze the composition, the microstructure and mechanical properties of coatings on steel.

R Riastuti (2018) et.al focused the study on corrosion behavior improvement of 316L stainless steel by molybdenum and aluminum coatings. Coating thickness is varied to analyze the good adhesion property and characterization is done using SEM, EDX, and microhardness testing. It is recommended by the authors to optimize the coating parameters which will increase the durability and performance of the component which is subjected to corrosive environments. S Ilaiyavel (2012) et.al studied the behavior of manganese phosphate-coatings on AISI D2 steel which is used in tool and die material. The manganese phosphate coating is achieved by forming a layer of manganese phosphate compound which involves chemical conversion of steel surface and different influencing parameters such as surface preparation, coating parameters and post treatment processes are analyzed to obtain uniform and adherent coatings. The wear resistance of the coated steel is evaluated using pin-on-disk and abrasive wear test. Chávez (2018) et.al investigated the microstructural and tribological behavior of coatings on AISI/SAE D2 grade tool steels using HVOF (High-Velocity Oxy-Fuel) thermal spraying process and GTAW (Gas Tungsten Arc Welding) process. The performance and wear resistance are enhanced and desired properties such as low porosity, high adhesion and improved mechanical properties are also achieved. It explored tribological behavior of the coatings such as surface damage resistance, wear and friction and the microstructural changes also examined.

L Bourithis (2005) et.al explored the various surface treatment methods such as heat treatments, surface engineering methods and coatings to enhance the wear behavior of low carbon steel. The authors introduced the modified strategies to enhance the wear resistance of low carbon steel surfaces. S. Piçarra (2019) et.al proved in their studies that the molybdenum coating improved the adhesion, stability and durability of staphylococcus aureus which is a common bacterium with nosocomial infections. N González (2020) et.al studied the effect of alumina coatings on steel using automated image processing techniques applied on isolated splat samples. Excellent thermal properties and wear resistance can be achieved by these coatings, but achieving defect free and uniform coating is challenging due to complexity involved in bonding between coating and substrate material during thermal spray process. Spray distance, powder feed rate and spray angle are identified the influencing parameters on thermal spray process using statistical techniques.

M.M.A. Bepari and Shorowordi K.M (2004) studied the effect of nickel and molybdenum coating on carburized and hardened low carbon steels to improve the wear resistance and also further addition of coating leads to improve the mechanical properties such as yield strength, tensile strength and impact toughness. Hwang (2004) et.al demonstrated that the MoO3-Al coating using plasma spray on the substrate exhibit a dense and well bonded structure with less porosity. Compared to pure Al coating, MoO3-Al gives better wear resistance and hardness. G. Bruno (2006) et.al presented the study on residual stress analysis of steel gear wheels with molybdenum coating using thermal spray coating process to find the influence of coating in wear resistance enhancement. The stress distribution of coating may affect the performance which is analyzed using residual stress analysis. Zhongsheng (2023) et.al investigated the effect of multilayer coating of MSZ(mullite-stabilized zirconia) and molybdenum using plasma spray and hot isostatic pressing to enhance the resistance which is able to withstand high temperature ablation in extreme conditions. Good bonding and less cracking are exhibited between the layers which leads to efficient stress transfer and good mechanical integrity.

It is observed that three-body abrasive wear research is lagging and less papers on abrasive particles impact on coatings. Therefore, this paper is aiming to assess and compare the effectiveness of molybdenum thermal sprayed coating system with the uncoated system in order to address the issue of wear rate in steel conveyor rollers. Based on the observations made from literature, stainless steel is the predominant choice of material for the rollers and the main dis advantage of the steel rollers is abrasion wear. To overcome this, among various techniques the plasma spray process is identified as effective technique to achieve effective bonding and less wear rate. A molybdenum coating is selected to enhance the wear characteristics in this study.

The main objective of this study is to find the coating influence on steel in wear environment and enhancing wear resistance by various grain size and by achieving the following objectives

- To provide molybdenum coating on stainless steel SS304 using plasma spray coating process and asses the coating properties
- To compare the performance of a Molybdenum coated steel with uncoated steel when exposed to a wear environment.
- To determine the optimal range of Molybdenum coating thickness on the substrate.

2 EXPERIMENTATION

The experimentation process is explained in the below sections.

2.1 Methodology

1. A comprehensive review of the literature is conducted to gain insights into various materials, their applications, coating substrates, and their characteristic properties.

2. Based on the findings from the literature survey and considering the desired properties, appropriate materials are selected and procured for the specific application.

3. Initially uncoated stainless steel SS304 characterized to assess the performance without coating using SEM, EDAX and hardness test.

4. Stainless steel SS304 is coated by Molybdenum using plasma spray technique.

5. Characterization of Molybdenum coated stainless steel SS304 samples using SEM, EDAX and hardness test.

6. Comparison of performance characteristics of coated and uncoated stainless steel SS304 in terms of microstructure, composition and hardness.

SS304 is austenitic steel of T300 series is selected as base material for this research which is widely used in different industrial applications because of its high corrosion resistance, high tensile strength and higher temperature resistance. It consists of minimum 18 % of chromium and maximum 0.08 % of carbon. The material is obtained from Sri Durga sales in Bengaluru. The purchased material had dimensions of 75 mm by 25 mm with a thickness of 8 mm which is shown in figure 1.

A steel strip measuring 25 mm by 8 mm was cut from the obtained material using a Bandsaw-Double column machine, with each piece being cut to a length of 75 mm. Subsequently, the cut specimens underwent hand grinding to achieve a flat surface along the edges, ensuring proper fitting into the specimen holder which is shown in figure 2. In this research, ASTM G65 standard test is used to evaluate the three-body abrasion. In this test, a dry sand/rubber wheel abrasion test is conducted using rubber wheel abrasion tester which is shown in figure 3.

The standard test specimen, with dimensions of 75*25*8, is securely mounted on a clamp, while the rubber wheel is pressed against it with a specified force using a lever arm. The setup configuration and details are shown in table 1.

Figure 1: Stainless steel-304.

Figure 2: Grinding.

Figure 3: Rubber wheel abrasion tester.

Table 1: Rubber wheel abrasion test rig specifications.

Test parameter	Details
Wheel	Chlorobutyl rubber A-60, dia
Sand	AFS50/70, Quartz sand
Sand Flow rate	350 gms/min
Pre-load on rubber	2.62 kg
Loading lever ratio	1:2.42
Happer capacity	15 kg

The abrasion wear of the test surface of the sample is regulated by the flow of grain in terms of grain size, speed or sliding distance and load. Grain size is varied from fine sand to coarse sand (200um, 300um and 600um), speed varies from 50rpm t0 150rpm (50 rpm, 100rpm and 150 rpm) and load varies from 25.702N to 72.986N(25.702N, 49.344N and 72.986N).

Figure 4: Dry Sand of different grain size (200, 300,600micron).

Mass loss is calculated by measuring the weight before and after the test using electro weighing scale which has 0,01 precision. The formula used to calculate the Mass loss is given below

Mass loss = Initial weight – Final weight

Then the volume loss is converted from Mass loss in cubic millimeters.

Volume loss = [Mass loss * 1000 / Density]

Then the Specific wear is calculated using

Specific wear rate = [(Volume loss) / (Load * Abrading distance)]

The obtained data from the test procedure for both the uncoated and coated specimens undergoes a series of calculation procedures, and their respective characteristics are considered for comparison.

3 RESULTS AND DISCUSSIONS

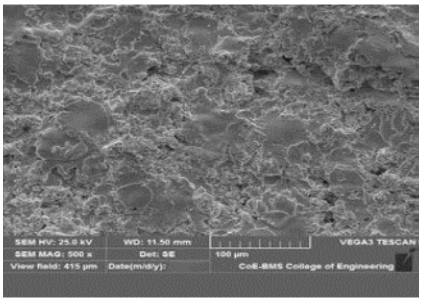

Figure 5a: SEM image of coated sample at 500X.

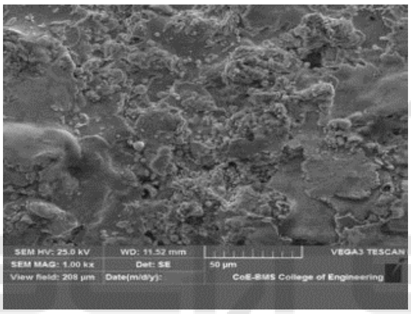

Figure 5b: SEM image of coated sample at1000X.

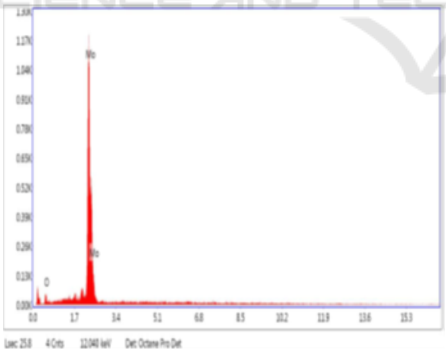

Figure 6: EDAX spectrum of coated sample.

SEM images of coated sample at different magnification such as 500X and 1000X are shown in figure 5 and EDAX analysis is performed to find the composition of coated sample which is shown in Figure 6. The spectrum obtained from EDAX provides confirmation of Molybdenum presence in coated sample. The atomic and weight percentage of the elements obtained through EDAX analysis is as shown in table 2.

Table 2: Atomic and Weight Percentage of Elements in Coated Sample.

Element	Weight %	Atomic %
MoL	89.28	58.13
OK	10.72	41.87

There are five different coating thicknesses along the length from SEM image are considered for the thickness measurement. The average thickness measured from the image is 110 microns from the Figure 7.

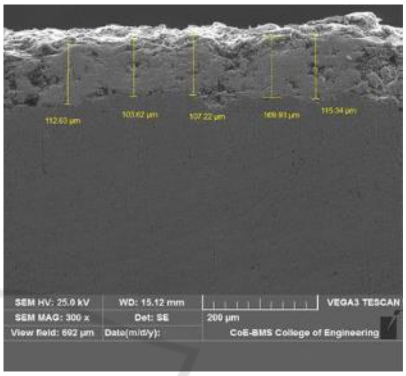

Figure 7: Coating thickness measured using SEM.

The uncoated specimen is clamped in specimen holder of rubber wheel abrasive tester and surface contact with rubber wheel is ensured. Sand hopper is filled with sand and the speed in terms of number of revolutions of wheel is fixed accordingly load is also placed on the lever arm. The results of 200, 300, 600 microns are tabulated in table 3, table 4 and table 5 which is shown below.

Table 3: Abrasion wear test results of uncoated specimen (200 microns).

Sl. no	Load (N)	Speed (rpm)	Initial weight (g)	Final weight (g)	Mass Loss (g)	Volume loss (mmt)
1	25.702	50	121.372	121.359	0.013	1.639
2	49.344	100	122.709	122.691	0.018	2.269
3	72.986	150	121.624	121.597	0.027	5.170

The table shows that least value of volume loss (1.639) was found for 50rpm and 25.072N load. the volume loss increased linearly for increased speed and load conditions.

Table 4: Abrasion wear test results of uncoated specimen (300 microns).

Sl.no	Load (N)	Speed (rpm)	Initial weight (g)	Final weight (g)	Mass Loss (g)	Volume loss (mmt)
1	25.702	50	122.534	122.519	0.015	1.891
2	49.344	100	121.156	121.134	0.022	2.774
3	72.986	150	122.262	122.218	0.044	5.548

The table shows that least value of volume loss (1.891) was found for 50rpm and 25.072N load. the volume loss increased linearly for increased speed and load conditions.

Table 5: Abrasion wear test results of uncoated specimen (600 microns).

Sl.n	Load (N)	Speed (rpm)	Initial weight (g)	Final weight (g)	Mass Loss (g)	Volume Loss (mmt
1	25.702	50	120.388	120.370	0.016	2.017
2	49.344	100	118.839	118.184	0.025	3.152
3	72.986	150	121.717	121.669	0.048	6.052

The table shows that least value of volume loss (2.017) was found for 50rpm and 25.072N load. the volume loss increased linearly for increased speed and load conditions.

The coated specimen is clamped in specimen holder of rubber wheel abrasive tester and surface contact with rubber wheel is ensured. Sand hopper is filled with sand and the speed in terms of number of revolutions of wheel is fixed accordingly load is also placed on the lever arm. The results of 200, 300, 600 microns are tabulated in table 6, table 7 and table 8 which is shown below.

Table 6: Abrasion wear test results of coated specimen (200 microns).

Sl. no	Load (N)	Speed (rpm)	Initial weight (g)	Final weight (g)	Mass Loss (g)	Volume
1	25.702	50	123.043	123.032	0.011	1.38
2	49.344	100	123.118	123.104	0.014	1.76
3	72.986	150	124.171	124.154	0.017	2.14

The table shows that least value of volume loss (1.387) was found for 50rpm and 25.072N load. the volume loss increased linearly for increased speed and load conditions.

Table 7: Abrasion wear test results of coated specimen (300 microns).

Sl. no	Load (N)	Speed (rpm)	Initial weight (g)	Final weight (g)	Mass Loss (g)	Volume Loss (mmt)
1	25.702	50	123.877	123.864	0.013	1.639
2	49.344	100	123.638	123.621	0.017	2.143
3	72.986	150	124.051	124.026	0.025	3.404

The table shows that least value of volume loss (1.639) was found for 50rpm and 25.072N load. the volume loss increased linearly for increased speed and load conditions.

Table 8: Abrasion wear test results of coated specimen (600 microns).

Sl. no	Load (N)	Speed (rpm)	Initial weight (g)	Final weight (g)	Mass Loss (g)	Volume
1	25.702	50	124.670	124.654	0.016	2.017
2	49.344	100	124.353	124.334	0.019	2.395
3	72.986	150	124.469	124.420	0.027	3.404

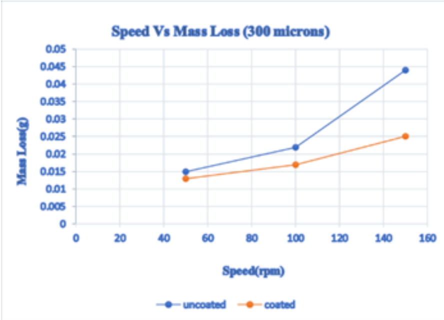

Figure 8: Load Vs Mass (200 microns).

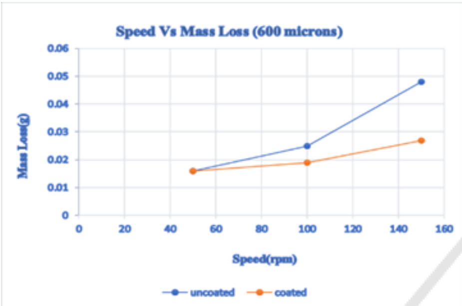

Figure 9: Load Vs Mass (300 microns).

The table shows that least value of volume loss (2.017) was found for 50rpm and 25.072N load. the volume loss increased linearly for increased speed and load conditions.

Load versus Mass loss graphs of both coated and uncoated samples are plotted for different grain size and shown in Figure 8-10.

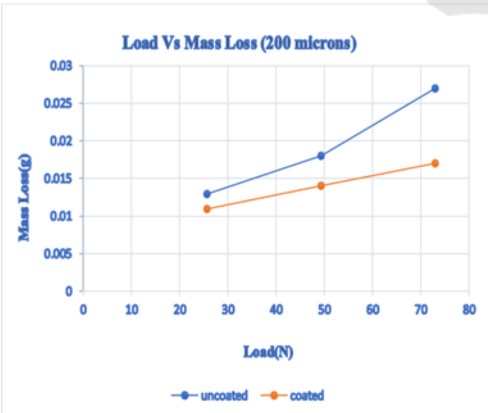

Figure 10: Load Vs Mass (600 microns).

Linear relationship between load and Mass loss is proved by all three graphs. Irrespective of Load and grain size, coated samples mass loss is less compared to uncoated steel samples which is proved by graphs. From figure 9, it is observed that mass loss for both coated and uncoated steel substrate are same for minimum load value. At minimum load, with higher grain size (600 micron) coating does not enhance the abrasive wear resistance.

Speed versus Mass loss graphs of both coated and uncoated samples are plotted for different grain size and shown in Figure 10-12. Linear relationship between speed and Mass loss is proved by all three graphs. Irrespective of speed and grain size, coated samples mass loss is less compared to uncoated steel samples which is proved by graphs. From figure 12, it is observed that mass loss for both coated and uncoated steel substrate are same for minimum speed value. At minimum speed, with higher grain size (600 micron) coating does not enhance the abrasive wear resistance.

At minimum loads and speeds, the difference in mass loss between the coated specimen and the uncoated specimen is negligible in comparison to higher loads and speeds. Coating has the influence only on higher loads, because of oxide layer generation in surface which acts as lubricant, which leads to less mass loss and abrasive wear.

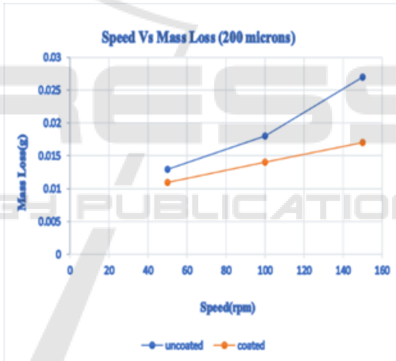

Figure 11: Speed Vs Mass (200 microns).

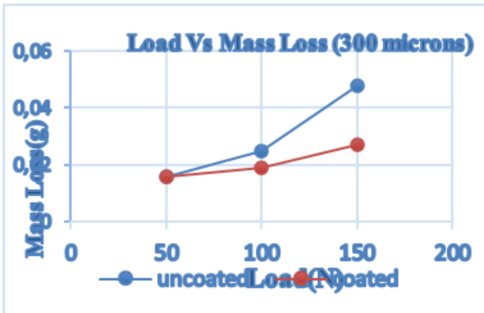

Figure 12: Speed Vs Mass (600 microns).

4 CONCLUSION

This paper focused on evaluation of coating performance of steel substrate which is used in conveyor rollers which works under highly abrasive environments. Main objective is to increase the three-body wear resistance by molybdenum coating using plasma spray technique. The results obtained from the experimental analysis proved the improvement in wear resistance after molybdenum coating. EDAX and SEM analysis are performed to composition identification and to find thickness of the coating. Enhanced resistance to mass loss indicates the improvement in wear resistance of molybdenum coated steel. Following observations are made from the experimental result and analysis

- The observed trend indicates that both the uncoated and coated samples exhibit a linear variation as the parameters such as speed, load, and grain size increase.
- At lower loads and speeds, the disparity in wear between the coated specimen and the uncoated specimen is negligible in comparison to higher loads and speeds.
- The findings indicate that when subjected to higher loads, an oxide layer is generated on the surface, acting as a lubricant and decreasing the friction coefficient. As a result, the presence of abrasives is reduced, leading to a decrease in mass loss and material wear.
- The experiment was conducted with a consistent coating thickness ranging from 100 to 150 microns. This approach can be expanded to create coatings of different thicknesses.

This research highlights the potential of molybdenum powder coatings to enhance the durability and lifespan of steel rollers in conveyor systems operating in harsh environments. The findings contribute to the development of effective strategies for reducing wear and optimizing the performance of mining and construction equipment. The experimentation was conducted using the atmospheric plasma spray process, but it is possible to expand the study by employing various thermal spray processes and assessing their performance.

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