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Sliding Wear Analysis of Thermal Sprayed Molybdenum Powder on D2 Steel Substrate

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ABSTRACT

The rolling process is one of the most important phases in the steel industry, and there will always be wear between the material travelling between the rolls and the guide roller. The guide roller's function is to guarantee that the material travels through the rollers with minimal damage and nearly a liner course. As a result, there is a provision for inserting a layer of coating to boost the productivity and life of guide rollers. The goal of this research is to create a Molybdenum-based coating for D2 tool steel, which is already used in the steel industry. The pin on disc wear test and Vickers hardness test were performed to compare the results of the uncoated substrate and the coated substrate to demonstrate that the coated substrate's wear resistance and hardness had enhanced compared to the uncoated substrate. Coated and uncoated specimens are placed in molds and polished against graft papers to provide a mirror-like finish for the thickness test and Vickers microhardness test. A high - resolution microscope found that the molybdenum coating thickness was 250 microns, with particle sizes ranging from 10 to 40 microns, and the Vickers hardness test revealed a 20% increase in hardness. The pin on disc wear test consisted of 54 trials using a full factorial design, with 27 coated and uncoated specimens. To achieve the desired results, three factors were chosen: Load, Sliding Velocity and time. The parameters for the three components were (1kg, 2kg, 3kg), (200 RPM, 400 RPM, 600 RPM), and time (15mins, 30mins, 45mins) accordingly. The diameter of the track was fixed at 40mm. The weight loss due to wear for the uncoated specimens was greater than that of the coated specimens after a total experimental duration of 27 hours of experimentation and 54 trials, showing an improvement in wear resistance.

Keywords - Atmospheric plasma spray process, D2 steel, Pin on disc, Molybdenum coating, Guide roller

1. Introduction

Rolling is a deformation process in which finished or semi-finished metal is passed through two rollers that rotate in opposite directions. A metal and two rollers which rotate in opposite directions to compress the metal between them are used in the rolling procedure. The main requirement is that the thickness between the two rollers be less than the initial thickness of the metal. The metal will move forward as it passes through the gap between the two rollers. The rolling process reduces metal thickness while increasing length and width while keeping overall volume constant. Before the metal is passed through the rollers, it must pass through guide rollers, whose function is to ensure that they remain linear and do not bend, reducing friction and heat generation. Guide Rollers are used to keep the metal specimen straight and reduce bending. While rolling mills are used in many industries, we will concentrate on the horizontal vertical mill (HV mill), which uses D2 steel as a guide roller material. As a result, we chose D2 steel as our base material to improve the wear resistance of D2 steel, which is the material used to make guide rollers. Chávez et al. [10] was used to obtain a graphical depiction of the hardness (HV) number of uncoated cold working D2 steel substrate. Alexander Paraschiv et al. [12] has thermal coated steel substrate using electric arc, atmospheric plasma spray and HVOF were investigated.

Mo coatings deposited by three thermal spray techniques such as EA, APS & HVOF methods are investigated by tensile bond strength and Vickers indentation tests in order to evaluate and correlate the two of most important and mechanical properties of the thermal sprayed coatings such as, cohesion strength and fracture toughness. They concluded that the tensile bonding tests indicate that the Mo coatings deposited by HVOF (HV) method had the highest value of bonding strength (43.3 MPa) followed by APS method (26.7MPa) and by EA method (19.2 MPa). Manjunath Patel G C et al. [7] has plasma coated Mo-Ni-Cr powder on stainless steel rod of dimensions 30mm height and 10mm diameter after coating the rod he performed Vickers micro – hardness test to know the hardness of both coated and uncoated rods. Wear test experiments were also conducted using pin – on – disc wear testing equipment to determine the dry sliding wear of both uncoated and coated rods. The wear loss experiments are conducted with different levels of load, sliding velocity and sliding distance on a track diameter. The results of micro hardness and pin – on – disc show that all plasma sprayed coatings showed statistically significant improvement. The results showed that coating hardness is 2.78 times better than that of the uncoated substrate and min wear rate was observed for the optimized conditions (load:30N, speed:350 rpm, sliding distance:3000m). Based on all of the data extracted from the literature survey and the fact that little work has been done to improve the hardness and wear resistance of D2 steel substrate, this project was carried out by coating D2 steel with Molybdenum powder to improve its hardness and wear resistance and, as a result, the life of guide rollers. of the paper should explain the nature of the problem, previous work, purpose, and the contribution of the paper. The contents of each section may be provided to understand easily about the paper.

2. Selection of Materials and Procurement

Based on literature review, the following materials are selected for the experiment and analysis of wear and hardness improvement. Some of the important features of each of the materials is listed as follows:

2.1 Base material – D2 Tool Steel

D2 steel is used for various works such as formation of rolls, tools and mouldings for plastic mould industries, knives, stamping dies, blanking dies and shear blades. D2 steel is a high carbon high chromium steel. In detail its chemical composition consists of Carbon (1.55%), Chromium (12%), Molybdenum (0.80%), Vanadium (0.90%), Iron, Silicon (0.25%), Manganese (0.35%). Since it is a relatively hard steel it has very good physical properties like high tensile strength, corrosion resistance and temperature resistance, but there is scope for improvement of hardness and wear resistance. Two metres of D2 steel with a diameter of 8.5mm was procured and then the 2metres of d2 steel was cut into 60 pieces of 30-35mm each as shown in fig 1.

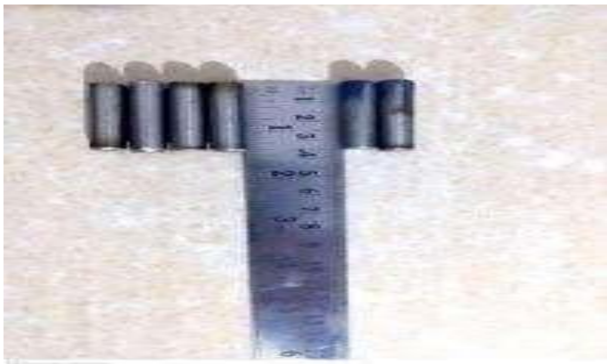


Fig 1: Procured D2 steel

2.2 Coating – Molybdenum Powder

Molybdenum has high refractoriness (high resistance to temperature and pressure). It has high wear resistance and hardness coefficient. It also acts as a good lubricant which can reduce friction. Hence, as shown in fig 2, Molybdenum was chosen as the coating material on D2 steel substrate to improve its hardness and wear resistance.

Fig 2: Molybdenum coated D2 steel

3. Experimentation

The goal of our research is to coat a D2 steel substrate with Molybdenum powder to improve its wear resistance and hardness. As a result, we devised the following experiments: Wire EDM procedure for flawless work parts to be inserted in a mould for thickness testing, Mold formation in a plastic cup., Thickness test, Vickers Micro - hardness test, Pin - on - disc wear test (Full factorial DOE).

3.1 Wire Cutting of Molybdenum Coated and uncoated D2 Steel Substrate:

The coated D2 steel substrate was subjected to wire EDM cutting process for measurement of coating thickness and Vickers micro – hardness. The operation was carried out and samples of size 4mm mid – section cut and 15mm cross – sectional cut was delivered after the cutting process. The images of the wire cut specimen is shown in fig 3.

Fig 3: Wire cut sample (4x15mm)

3.2 Mould Preparation

The wire cut specimen whose coating thickness was to be measured was placed in a one – inch CPVC pipe such that the specimen as well as the pipe surface lie flat on a surface. A mixture of cold setting powder and the cold setting liquid was poured in paste form which solidified after 20 minutes.

3.3 Polishing

The polishing of the surface becomes very crucial since any kind of the smallest irregularities affect the micro – hardness. The specimen was first polished on a double disc polishing machine using sandpapers of 4 grit sizes 200, 600, 800 & 1200 in the increasing order finished off with a velvet cloth to get a mirror like finish. After providing a rough finish on all 4 sand papers, the disc was mounted with a velvet cloth and operated in the presence of alumina paste for providing a mirror finish on the specimen. The velvet cloth mounted on the disc and the polished specimen with mirror like finish is shown in the fig 4.

Fig 4: Polished specimen

3.4 Coating thickness measurement

The coating thickness of the polished specimen was determined using a high – resolution microscope at 10X magnification, as shown in fig 5. Five different coating thickness measurements along the length of the coating were taken and their average was calculated using Envision software.

Fig 5: High – Resolution microscope for Coating thickness measurement

3.5 Vickers micro – hardness test

The Vickers Micro – Hardness test was performed using Economet VH- IMDX (Chennai Metco) at PMR Laboratory, PES University as shown in figure 6. The spots at which the 4 indentations were made was identified using a 40x magnification and cross – referenced with the high – resolution microscope to measure the length of diagonals of each of the four indentations, then a formula was applied using these lengths to find the HV number. A diamond shaped indented was used to make 4 consecutive indentations on the polished surface and the coating under a load of 1 kg and dwell time of 10 seconds. The average hardness for coated and uncoated material was calculated by taking the average HV number of all 4 readings.

Fig 6:Vickers micro – hardness tester

3.6 Pin on disc wear test:

As shown in fig 7 along with its parameters in Table 1, Pin – on – disc is frequently utilized to examine material sliding behavior and pertinent wear mechanisms under various tribological settings. The method has also been successfully applied to the analysis of materials for brake systems in order to gain particular information on wear processes. In this study, we will perform a pin – on – disc wear test on both uncoated D2 steel substrates and Molybdenum coated D2 steel to assess the improvement in wear resistance caused by Molybdenum coating. The fundamental concept behind improving the wear resistance of D2 steel is to extend the life of D2 steel guide rollers used in rolling industries. We chose three factors to get the desired results: load, sliding velocity, and time. The parameters are (1,2,3) kg, (200,400,600) RPM & (15,30,45) minutes. The track diameter was set at 40 mm and 54 trials were executed comprising 27 coated and 27 uncoated specimens to achieve full factorial DOE (Design of Experiments).

Fig 7 : Pin – on – disc wear test rig

Table 1: Pin – on – disc wear test rig parameters

Make	Ducom
Model	TR201LE
Wear Disc Diameter	100mm
Thickness	6 – 8mm
Depth of Thread	150mm
Pin Diameter & Length	4 – 8mm & 20 – 30mm
Disc Speed	Min 100 rpm – Max 1000rpm
Normal Load	Min 10N – Max100N
Frictional Force	Max 100N
Wear	0 to 2000 Micron

4. Results & Discussions

4.1 EDAX

The EDAX spectrum obtained as shown in figure 8, confirms the presence of Molybdenum as the coating material. Oxygen presence is due the high temperature during the plasma process where molybdenum may have oxidized.

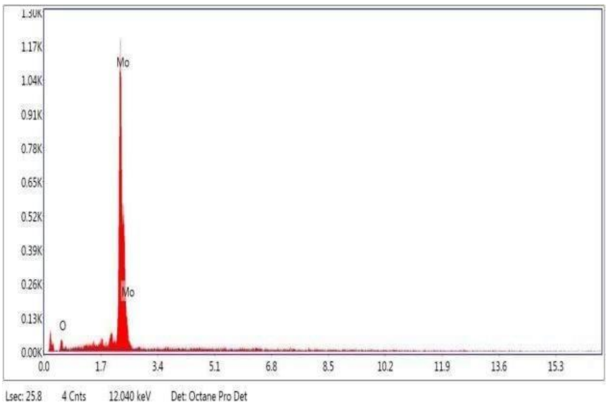
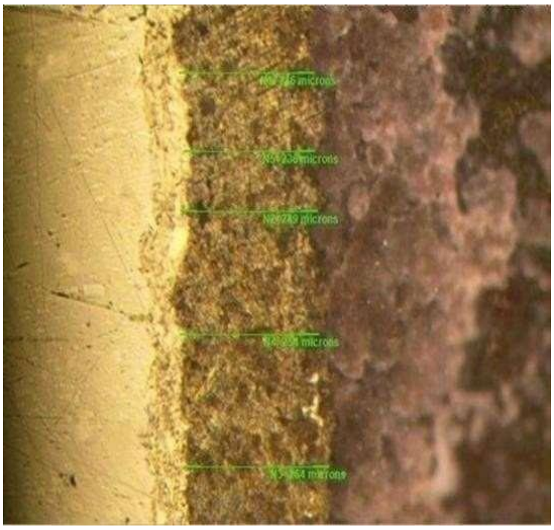


Fig 8: EDAX spectrum of Coated Sample

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

ELEMENT	WEIGHT%	ATOMIC%
Mo L	89.28	58.13
O K	10.72	41.87



4.2 Coating thickness measurement results

The polished coated specimen was placed under the microscope and using Envision software. Five different coating thickness values at 10X zoom along the length of the coated specimen were measured. A bond coat of thickness 10 microns – 50 microns is present right below the Molybdenum coating and the particle size of the Molybdenum coating ranges from 10 microns to 40 microns. The average coating thickness of Mo powder was found to be 250 microns as shown in fig 9.

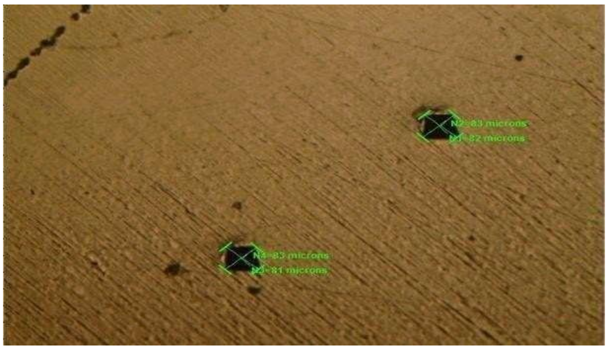


Fig 9: Coating thickness measurements

4.3 Vickers micro hardness test results

The micro – hardness test was performed on both the uncoated specimen (D2 steel) and the Molybdenum coating to evaluate the increase in hardness. The micro hardness of the D2 steel substrate was found to be 275HV and the micro – hardness of Molybdenum coating was found to be 329 HV. Which resulted in a 20% increase in micro hardness. 4 indentations were made on both D2 steel and Molybdenum powder coating (shown in figs 10 & 11) after which they were kept under a microscope to determine the diagonal length of the indentations. The diagonal length of each of the four indentations in D2 steel as well as Molybdenum powder were inserted in the formula: 1.854 X P/D^2 =HV (D is average of d1 and d2). After getting 4 HV values for both coated and uncoated specimen the average was taken to determine the increase in hardness which proved to be a 20% increase in hardness.

Fig 10: Diagonal Lengths of Indentations inD2Stee

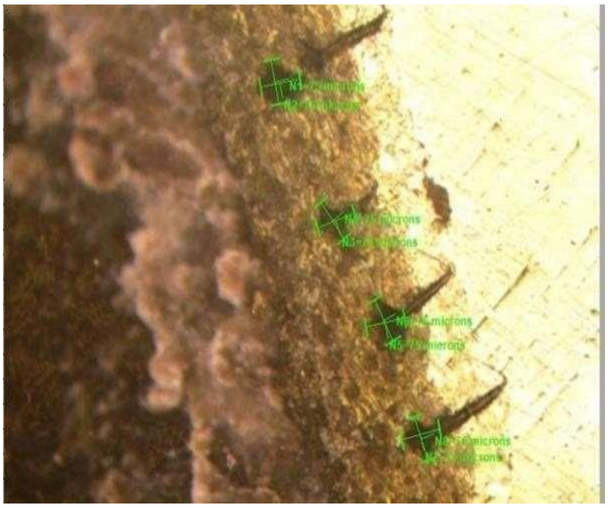


Fig 11:Indentations in molybdenum coating layer with diagonal length readings

4.4 Pin – on – disc wear test results:

The pin – on – disc wear test was performed on both the uncoated specimen (D2 steel) and the Molybdenum coating to evaluate the increase in wear resistance. Before the commencement of experiments, the specimens(pins) were flattened at the ends to obtain optimal wear test results. A total of 54 trials were conducted based on the Design of Experiments obtained through Minitab software. The tests were conducted using three parameters, namely: Load (1,2,3 (Kg)), Sliding Velocity (200,400,600 (RPM)) and Time (15,30,45 (minutes)). The disc material was EN8 with a hardness (HRC) value of 60. The results of pin – on – disc wear test is analyzed in the form of graphs as shown in figs 12, 13 and 14:

Fig 12: Weight loss vs Varying Load with 200 RPM & 15 Minutes Run Time asConstants

In fig (12), weight loss vs varying load, the amount of friction force is affected by the load and the sliding speed. When the load is increased, the weight loss due to wear increases significantly. The tangential shear stress generated during sliding increases as the loading increases. As a result, the weight loss due to wear for coated and uncoated substrates increases almost with load.

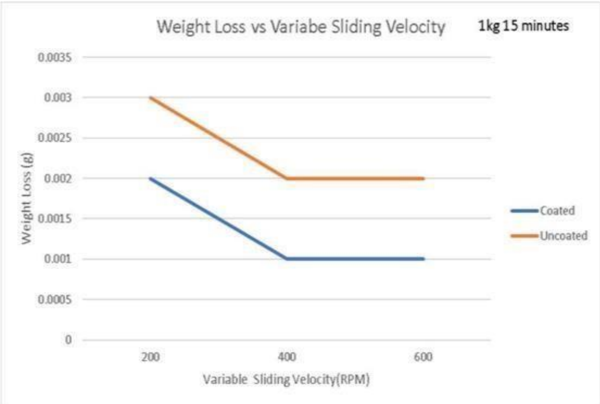


Fig 13: Weight loss vs Varying Sliding Velocitywith 1kg and 15 Minutes Run Time asConstants

In fig (13), weight loss vs varying sliding velocity, as the sliding speed increases, the weight loss of the specimen decreases which is supported by literature survey of Essay et. Al [13]. This could be due to the disc's high rotation speed, which reduces the contact chance between the disc and the pin, lowering the wear rate. However, by lowering the RPM, the pin and disc surfaces become more in contact. As a result, there is a high likelihood of wear.

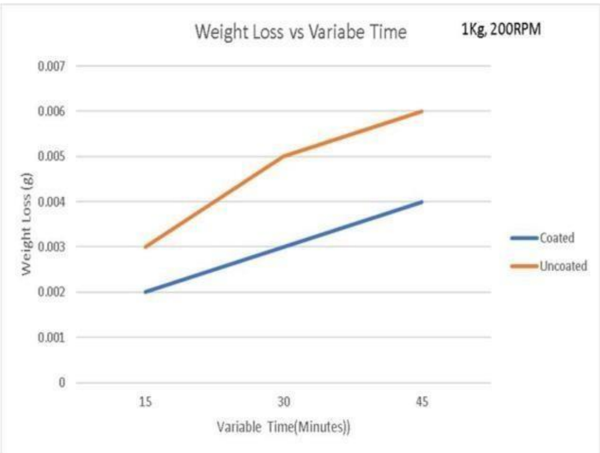
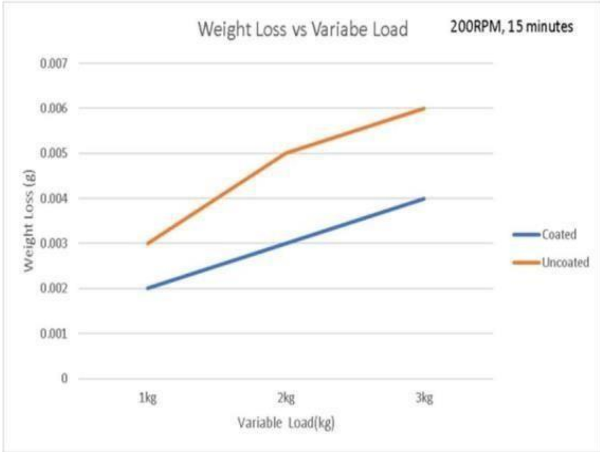


Fig 14: Weight loss vs Varying Contact Time with 1kg and 200RPM as Constants



In fig (14), weight loss vs varying contact time, Frictional force increases as contact time increases, resulting in a consistent increase in weight loss due to wear for both coated and uncoated substrates. Weight loss is less for coated substrates over longer contact times than for uncoated substrates, indicating an improvement in wear resistance.

5. CONCLUSION

Pure Molybdenum of 250 microns thickness is coated on D2 steel substrate using thermal spraying process. The average hardness of the coated specimen is measured to be 20% higher than the uncoated specimen. In most cases weight loss due to wear is directly proportional to the increase in load and contact time and inversely proportional to the sliding velocity with varying parameters of load, rpm and according to the weight loss method of calculating wear resistance ,the weight loss due to wear of coated substrate when compared to that of uncoated substrate was lesser by 39%, 46%, and 43% at 15 minutes, 30 minutes, and 45 minutes contact time respectively. The results of the pin on disc wear test experiment revealed that the weight loss for uncoated specimens is more than the weight loss for coated specimens, showing an improvement in wear resistance.

The experimentation has been carried out with pure molybdenum powder as the coating material and the work can be extended with other available high refractory coating materials or various blends along with pure molybdenum coating.The coating material thickness and the thermal spray process can be varied which could lead to better performance of the coatings.

A conclusion section must be included and should indicate clearly the advantages, limitations, and possible applications of the paper. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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