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RESEARCH

Investigation of Wear Coefficient of Manganese Phosphate Coated Tool Steel

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A B S T R A C T

In recent years the properties of the coating in terms of wear resistance is of paramount importance in order to prevent the formation of severe damages. In this study, Wear coefficient of uncoated, Manganese Phosphate coated, Manganese Phosphate coated with oil lubricant, Heat treated Manganese Phosphate coated with oil lubricant on AISI D2 steels was investigated using Archard's equation. The wear tests were performed in a pin on disk apparatus as per ASTM G-99 Standard. The volumetric wear loss and wear coefficient were evaluated through pin on disc test using a sliding velocity of 3.0 m/s under normal load of 40 N and controlled condition of temperature and humidity. Based on the results of the wear test, the Heat treated Manganese Phosphate with oil lubricant exhibited the lowest average wear coefficient and the lowest wear loss under 40 N load.

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1. INTRODUCTION

The Principal aim of conversion coating is confer anti-welding characteristics although it may also cause a slight increase in the surface hardness [1]. High carbon high chromium steels are used in application requiring tremendous wear resistance in tool and die making industries. Phosphating is chemical conversion treatments which produce a porous surface layer of crystalline phosphate [2]. This process relating a reaction between a solution and a metal surface such that the coating derives partly from the solution and partly from the substrate [3]. Phosphate coatings are normally formed by immersing iron into an aqueous solution of phosphoric acid and manganese carbonate [4]. Manganese Phosphate coating are produced by chemical conversion and the main component of the film is hureaulite $(Mn\ Fe)_5.H_2(PO_4)_2$. Due to its economy, speed of operation, ability to afford excellent corrosion resistance, wear resistance, adhesion and lubricative properties, it plays a significant role in the industries [5-9]. To understand the wear properties of different types of coating wear test are carried out with suitable wear testing techniques. The pin on disc test is the established method universally used for wear experiment. To assist the measurement the pin is usually the wearing member that has lesser hardness. Wear coefficient is superior parameter though wear loss and Friction coefficient are frequently used for studying the wear characteristics of test specimen. It is so because the wear coefficient takes into account not only the wear rate, but also the applied load, and the hardness of the pin [10]. L.J. Yang [11] proposed new moving pin technique that is allowed to move across most of the disc space during testing at the same time maintaining the constant speed by varying the distance and rotational speed. The wear coefficient values obtained is not varying with the disc materials used. The variation is about 4% and 17% of the mean value obtained from the moving pin and stationary pin tests, respectively. Therefore more reliable wear coefficient values are obtained from the moving pin test than from the stationary pin test. Reasonably, the moving pin technique has given to a higher wear rate and a slightly higher wear coefficient. This is due to a enhanced work-hardening effect with the use of more virgin disc surface area in the wear testing. C.S. Ramesh [12] investigated on wear coefficient of Al6061–TiO2 composites. Based on the result Al 6061–TiO2 composites exhibited higher hardness, lower wear coefficient when compared with matrix alloy. M.A. Chowdhury et al [13] observed that the presence of normal load and sliding velocity affects the co effect of friction considerably. The values of friction coefficient decrease with the increase in normal load for copper-copper, copper-brass, brass-brass and brass-copper pairs. V. Bria et al [14] explained that the role of aramids fibers in the composite on increasing the wear resistance of materials while the graphite particles appearing from carbon fibers breaking acts as dry lubricant. The aim of this paper is to find the volumetric wear loss and wear coefficient of uncoated, Manganese Phosphate coated, Manganese Phosphate coated with oil lubricant and heat treated Manganese Phosphate coating with oil lubricant on AISI D2 steel substrate.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

The High carbon and high chromium tool steel was used as substrates. The chemical composition of the materials is given in Table1.

2.2 Specimen

The specification, initial hardness values and surface roughness for the pin and disc are listed in Table 2. The four types of pins were prepared such as uncoated, Manganese Phosphate coated, Manganese Phosphate coated with oil lubricant and heat treated Manganese Phosphate coating with oil lubricant for the comparison of the wear coefficient parameter.

2.3 Manganese Phosphate Coating

The Manganese Phosphatation consists of three basic sequences are cleaning, refining and phosphating. The refining bath consisting of Mn Phosphate solutions favours the deposit of a fine layout of metallic salts onto the steel surface. S. Ilaiyavel et al [15] explained the details of Manganese Phosphate coating procedure used in this present study. The coating thickness is around 1.5 to 2 g/m^2 by an immersion process. The coatings produced are single phase and the only coating forming mineral is hurealite i.e. mixed iron-manganese orthophosphate, having the chemical formula as: -$(Mn,Fe)_3\ (PO_4)_2.2(Mn,Fe)HPO_4.4H_2O$.

Table 1. Chemical composition of the material [wt. %] analysed by optical emission vacuum spark spectrometer.

Elements	C	Si	Mn	Cr	Ni	Mo	V	Ti	S	P	Fe
Percentage	1.50	0.41	0.74	12.01	0.01	1.01	0.27	0.01	0.03	0.03	Balance

Table 2. Specification, hardness and surface finish for pin and disc.

Description	Material	Hardness HRc	Surface Roughness (R_a) Microns
Pin (8 mm dia, 15 mm long)	D2 Steel (As received)	20	0.1
Disc (Dia 60 mm, Thickness 10mm)	D2 Steel Hardened and Tempered	60	0.1

2.4 Heat treatment after the Coating

The coated steel substrate is heated slowly up to 450 ^{0}C and kept around 15 mins duration. It is then cooled in the furnace to reach room temperature. The steel substrate surface is not affected by the heating and furnace cooling.

2.5 Lubrication

In this experiment 20W40 oil is used as a lubricant. Table 4 shows the properties of the lubricant. After coating prior to wear testing both coated and heat treated and only coated pins are dipped into oil lubricant for around 15 to 20 mins at room temperature. Lubricating oil creates a thin separating film between surfaces of adjacent moving parts [16] .This minimizes direct contact between them, decreases heat caused by friction and reduces wear.

Table 4. Properties of lubricant.

Kinematic Viscosity at 100 ^{0} C	13.5-15.5
Viscosity Index, Min.	110
Flash point (COC), ^{o}C Min.	200
Pour point, ^{o}C Max.	(-)21

2.6 Wear testing

Wear performance of materials are commonly obtained from testing carried out in pin-on-disk equipment to ASTM G99 standard procedure. It gives a laboratory standard method to carry out sliding and abrasion wear tests. The tests were carried out under 40 N applied load and for sliding velocity of 3.0 m/s for a constant sliding radius of 15 mm. During testing the tangential force was measured by a set of load cell and monitored by Computerised data acquisition system. In all the cases the friction coefficient and volumetric wear loss of the pin were estimated by taking three pins average value.

3. RESULTS AND DISCUSSION

3.1 Volumetric Wear loss

The variation of volumetric wear loss with sliding distance is shown in Fig. 1. With increase in sliding distances there is higher volumetric loss for uncoated pins, at longer sliding distance higher rise in temperature on both the sliding surfaces. This causes the heavy deformation at higher sliding distance. Manganese Phosphate coated pins shows slight higher volumetric loss after 600 m sliding distance, because of partly removal of coating after longer sliding distances at constant load 40 N. Both Manganese Phosphate coated with oil lubricant and Heat treated Manganese Phosphate coated with oil lubricant show lowest volumetric loss, because of very less coefficient of friction achieved by the presences of oil lubricant. S. Ilaiyavel et al [8] expressed that Manganese Phosphate coated with oil lubricant pins show very low coefficient of friction about 0.1 to 0.2. Heat treated Manganese Phosphate coated with oil lubricant pins show the same coefficient of friction even at higher the loads and longer sliding distances. Because of heat treatment more micro cracks present in the crystal which are perpendicular to the substrate surface. Fig. 2 shows micro graph of heat treated Manganese Phoshate coated AISI D2 steel. These cracks occur due to the loss of water and when the dehydration is completed, the maximum oil retaining capacity also improved.

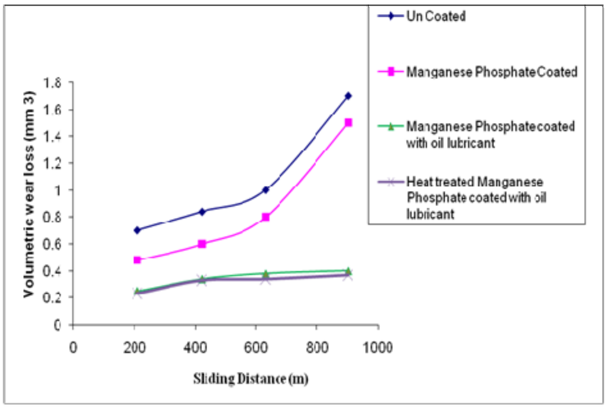

Fig. 1. Volumetric wear loss vs sliding distance at velocity of 3.0 m/s.

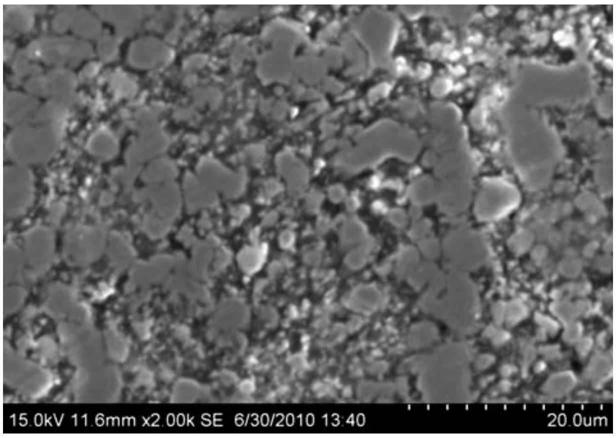

Fig. 2. Micro graph of heat treated manganese phosphate coated AISI D2 steel.

3.2 Wear Coefficient

Steady state wear was proposed by Archard V= KsPL/3H where V is the volumetric loss of material after sliding for a distance L and load P normal to the wear surface. H is the Brinell hardness number of the pin while Ks a dimensionless standard wear coefficient. For known values of V, P, L and H the standard wear coefficient can be calculated from the equation Ks=3HV/PL. Volumetric wear loss can be calculated from the weight loss W and the density. L.J. Yang [10] expressed that the higher initial running – in wear rate, has a higher value initially in the transient wear regime and will reach a steady – state value when the wear rate become constant. Figure 3 shows the variation of wear coefficient with sliding distance. It is observed that wear coefficient decreased with increased sliding distance. However under the same conditions Heat treated Manganese Phosphate coated with oil lubricant shows lowest wear coefficient. The major reason is the lowest volumetric loss is recorded. The annealing treatment increase the micro cracking and also increases oil retention. Oil can react at the grain boundaries of the Heat treated coating to form a beneficial adherent film, increasing the wear resistance under oil lubricating conditions. P.H. Hivart et al [17] also expressed that the dehydrated and transformed new coating surface has a better reactivity towards lubrication than the initial Huralite.

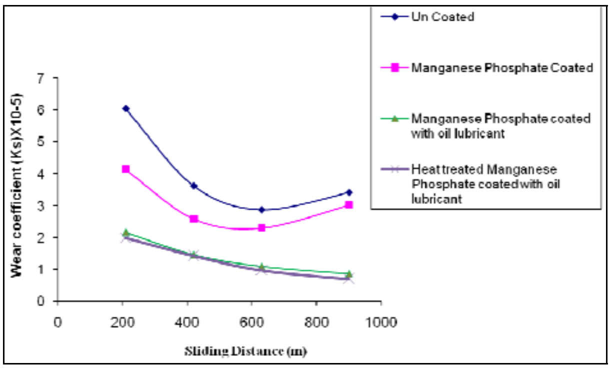

Fig. 3. Wear coefficient vs sliding distance at velocity of 3.0 m/s.

4. CONCLUSIONS

The Wear coefficient of uncoated, Manganese phosphate coated, Manganese phosphate coated with oil lubricant and Heat treated Manganese phosphate coated with oil lubricant pins were examined under 40 N loads at sliding velocity of 3.0 m/s using pin on disk apparatus and the results are summarized as follows:

- Increased sliding distance resulted in higher volumetric loss and lowered the wear coefficient for, un coated, Manganese phosphate coated, Manganese phosphate coated with oil lubricant and Heat treated Manganese phosphate coated with oil lubricant pins.
- Heat treated Manganese phosphate coated with oil lubricant pins exhibited the lower coefficient friction and lower wear coefficient as compared with uncoated, Manganese phosphate coated, Manganese phosphate coated with oil lubricant pins.
- The heat treatment may increase the quantity of oil retained through the micro cracking phenomenon which increases oil retention. Oil can react at the grain boundaries of the Heat treated coating to form a beneficial adherent film, which increase the wear resistance under oil lubricating conditions resulting lower the wear coefficient.

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