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Multilayer PVD Surface Engineered Coatings for Sheet Metal Forming Tools

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Abstract

Objectives: In this paper, the surface of sheet metal forming tool is coated by physical vapour deposition with molybdenum disulphide with the aim of preventing their premature failure. **Method/Analysis:** Physical Vapor Deposition (PVD) coatings have held a prominent position in this field for the last one decade. Although low friction coatings are deposited with good adhesion to the substrate there is a possibility of surface coating with poor adhesion. In the present paper molybdenum disulphide was deposited on D2 tool steel specimen by thermal evaporation. The effect of multilayer on microstructure, micro hardness, coating thickness and film adhesion were studied. **Findings:** It had been found that multilayer coatings has provided with improved adhesion, non columnar microstructure and harder surfaces. **Improvement:** The multilayer PVD MoS_2 coatings provide a hard and wear resistant surface on sheet metal forming tool and improve its life.

Keywords: Forming Tool and Coating, PVD, Tool Steel

1. Introduction

Demand for surface engineered coatings has been growing since the last few years on the back of rapid industrialization and recovery of global economy. Material properties can be improved by different surface coatings. As a result of severe friction between the tool and sheet, quality of formed products is affected. Surface coating on the forming die has been effectively used to control the level of friction force, minimize the friction wear and enhance the life of dies. D2 grade tool steel is usually used as material in sheet metal forming dies. Steel under different processing conditions with different coatings demonstrate different tribological and mechanical properties[1].

For several years it has been possible to deposit hard and wear-resistant coatings onto steel substrates using various Physical Vapor Deposition techniques. But the typical hard coatings are rarely used nowadays. These surface coatings are having considerable friction and do not give any protection for the opposing surface. If the surface roughness of the coating is high, then they can cause abrasion and wear of the opposing surface. Therefore, there has been a lot of emphasis on the research of soft coatings to prevent friction and wear. In order to provide the best wear protection against sliding, it is necessary to use a solid lubricant coating with less friction and protect the opposing surface and to provide a minimum friction transfer film on the opposing surface[2]. Surface roughness, hardness and thickness of coatings and debris at the interface are the four important parameters which control the tribological contact behavior.

MoS_2 is commonly used as a solid lubricant because of its low frictional properties. MoS_2 can be used effectively in high vacuum environments and as a result can be used for space applications. The structure of MoS_2 is in the form of a triangular prism. The sulfur atoms occupy the corners of prism. The crystal structure is anisotropic. The weak Vander Vaal forces between the layers of MoS_2 results in low shear strength and hence low friction in the sliding direction.

Recently, novel MoS_2 coatings with a combination of high hardness and low friction were developed. The high hardness combined with low friction gives very less wear rates and the properties of the coatings combined with the adhesion leads to very high load-bearing capacity. ITiN/TiAIN-MoS_2/MoS_{2}-Ti multilayer composite coatings

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were produced by magnetron sputtering. These coatings produced low wear and friction coefficient[3]. Multilayer films of WS_2/MoS_2 were fabricated by magnetron sputtering and low temperature ion sulphurizing. It was found that multilayer films showed superior wear resistance when compared with single layer films[4]. A titanium interlayer was introduced to MoS_2 film to improve adhesion and wear resistance. It was observed that that wear life reduced when titanium weight percentage is increased above 10% in films[5]. Different surface modification techniques to improve galling resistance of forming tools were compared. Nitriding combined with polishing and DLC coating is suggested as the best coating to improve galling resistance of forming tool[6]. In this paper, molybdenum disulfide was deposited of D2 tool steel by thermal evaporation and coatings were characterized.

2. Experimental

2.1 Sample Preparation

AISI D2 alloy steel was selected as specimen. The specimen was fabricated to a size of 50 X 12 X 1 mm and heat treated hardness of Rockwell C Hardness value of 59. The surface finish of specimen was improved by grinding and polishing with silicon carbide emery paper. After polishing the specimens were cleaned with acetone before deposition.

2.2 PVD Coating Unit

The Physical Vapour Deposition system accommodates a vacuum pump along with all the electrical components required for deposition process. The evaporation chamber is manufactured from stainless steel with a glass window for inspection of deposition process. High vacuum is created by a diffpack pump and a rotary vacuum pump. The pumping system and the evaporation chamber are isolated by a valve.

Power connections were given to filament holder through a set of electrodes. The filament was located in such a way to ensure uniform distribution of the evaporation. This resistance filament heater is used to evaporate the source material molybdenum disulphide. A heating element was provided to raise the temperature of specimen. A thermocouple is used to measure specimen temperature. The digital thickness monitor made of quartz crystal provides a direct display of film thickness and deposition rate.

A shutter control system was used to get automatic control of coating film thickness. When the deposition thickness reaches a pre-programmed value, the shutter valve will automatically close. The physical vapour deposition system was started up by switching on the power supply and vacuum. The pre-programmed option on the deposition selection meter was activated. The film thickness of 1 micron was set. Then the density and impedance slots were selected from manual. For Molybdenum density value is 10.8 and impedance is 34.36 (as given by coating PVD equipment manufacturer). The D2 steel samples were clamped in to the substrate holder and MoS_2 were loaded in to the filament boat. The bell jar was closed and the evaporation chamber was pumped on. When the deposition had started, the open shutter is pressed on deposition meter by flipping shutter switch down. The current was changed to maintain the desired deposition rate. At the desired thickness the shutter was closed. The current was steadily ramped down. The thermal evaporator equipment was switched off and the jar is opened and deposited sample removed.

The chemical composition of the film depends on the purity of molybdenum disulphide and the quality of the vacuum. Thicknesses of the film vary due to the geometrical parameters of the evaporation chamber. The working pressure in the vacuum chamber was kept at 5×10^{-6} Pascal. The sample was heated to 160°C.

2.3 Film Characterization

The films were characterized in terms of coating thickness, hardness and adhesion and microstructure[7]. Micro hardness measurement of the coatings was conducted by Shimidzu Vickers Micro hardness machine. The thickness of the coating (single and multi-layer) is measured using Spectroscopic Ellipsometry technique. Figure 1 shows the photograph of Ellipsometer. The microstructure images are taken from Optical Microscope at different magnifications, 100X, 200X, 500X and 1000X, SEM (Scanning Electron Microscopy) images and EDAX Analysis (Energy Dispersive X-ray). Spectroscopic ellipsometry is an optical technique mostly used to measure film thickness.

3. Results and Discussion

3.1 Ellipsometry Results

The average coating thickness and the refractive index for single and multi-layer coatings were found using

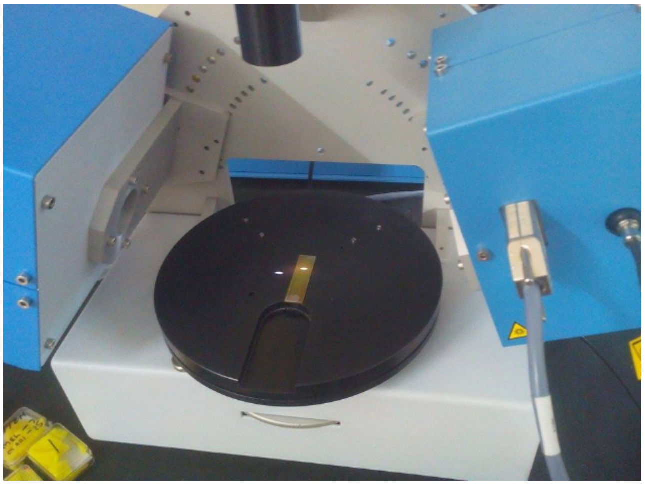

Figure 1. Photo of spectroscopic ellipsometer.

Table 1. Ellipsometry results

	Average Coating thickness (nm)	Refractive index (n)
Single Layer	233.844 ± 6.496	1.555
Multi Layer	367.057 ± 11.381	1.565

this technique. The Refractive index vs. Photon Energy graph is plotted showed by the solid line and the dotted points represent the values fitted according to the New Amorphous Model. The results are given in Table 1.

3.2 Micro Hardness

The hardness of the coated samples was taken from Shimidzu Vickers Micro hardness machine. The testing load applied to the coatings was .05 kgf and time for which the load is applied is 30 sec. The average value of three readings is taken and it was found to be Hv865 for single layer coatings and Hv884 for multilayer coatings. The micro hardness value of multilayer MoS_2 coatings indicate that multilayer coatings have the potential to offer good wear resistance to tool steel by increasing the hardness

Film substrate adherence test is conducted. MoS_2 Single layer Coatings showed total failure at 53 N, with delamination starting at 32 N. Multilayer coatings showed total failure at 81 N with delamination staring at 45 N. The examination of the deposited samples through microscope after the scratch test has confirmed this result. Multilayer coatings provide a strong metallurgical bond with substrate when compared with single layer coatings and this result is confirmed by early researchers[8–11].

3.3 SEM and EDAX Results

Figures 2 and 3 show the optical micrographs of single layer and multilayer MoS_2 coatings. Multilayer coatings show more compound clusters distributed randomly when compared with single layer coatings. Figures 4, 5 and 6 shows the SEM images of multilayer MoS_2 coatings under different magnifications. The SEM images has shown a non columnar morphology. The SEM images also reveal that compound clusters were embedded in to the carbon matrix. The embedded clusters are crystalized and dispersed randomly in carbon matrix which is confirmed by scan electron microscopy observation. Small cracks are observed in the SEM microstructure of MoS_2 coatings.

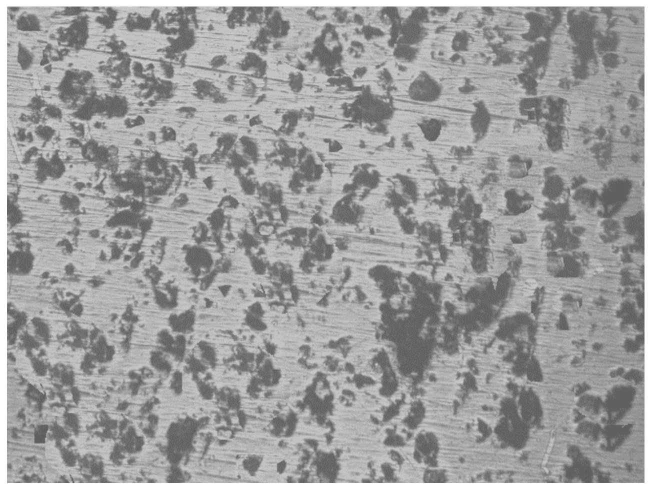

Figure 2. Optical micrograph of single layer MoS_2 coatings.

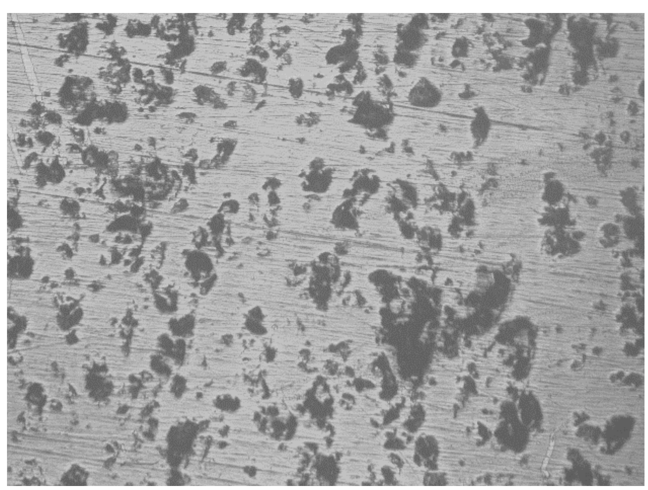

Figure 3. Optical micrographs of multilayer MoS_2 coatings.

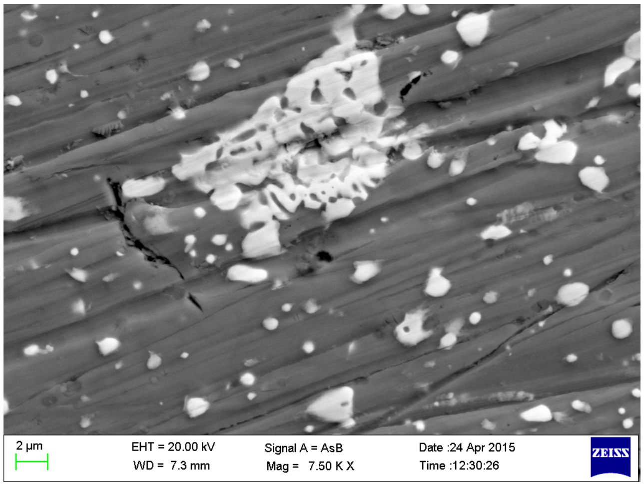

Figure 4. SEM image of multilayer MoS_2 coatings.

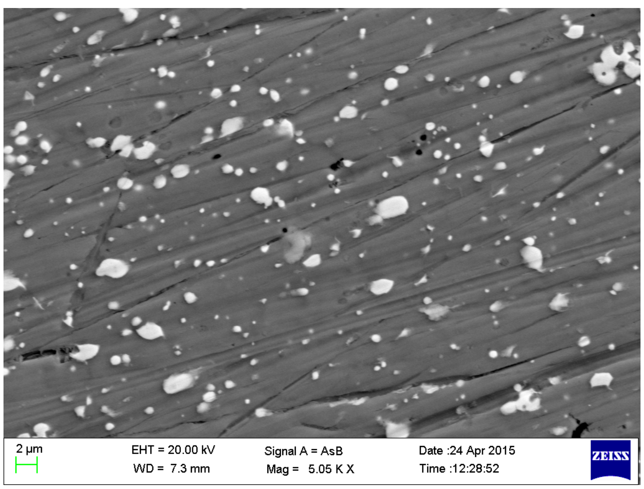

Figure 5. SEM image of multilayer MoS_2 coatings.

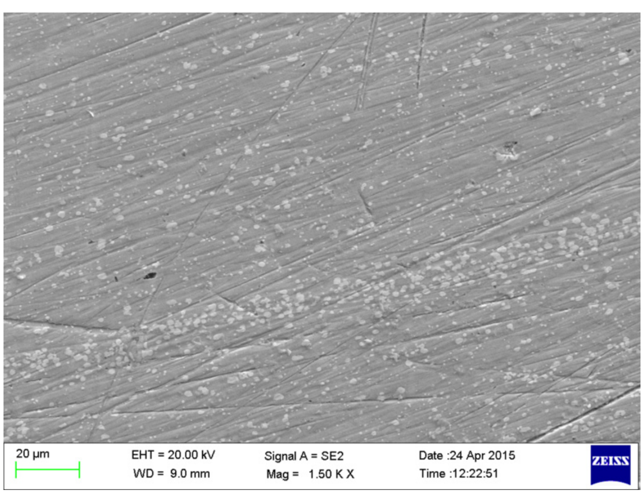

Figure 6. SEM image of multilayer MoS_2 coatings.

Electron Dispersive Spectroscopy (EDAX) was taken for uncoated and coated specimen. A significant increase for Molybdenum (by 24.5wt % and 13.44At %) and Sulfur (by 8.75wt % and 14.88At %) was observed in coated samples. The other substrate elements Fe, C and W peaks were detected in EDAX Spectrum of MoS_2 coated sample which were very low in concentration. This indicates that these elements were also diffused in the coating at very low concentration. Oxygen was not detected in the spectrum which shows that porosity is low in the coating. This is due to low temperature nature of thermal evaporation process.

4. Conclusions

MoS_2 thin film coatings were deposited on D2 tool steel using a relatively simple thermal evaporation technique. The microstructure was studied using Optical Microscope, SEM and EDAX analysis. The coating thickness was measured using Spectroscopic Ellipsometry. Micro hardness test of coated samples reveal that micro hardness of multilayer coatings were more than that of single layer coating. The film adherence test also revealed that a multilayer PVD coating has provided a good metallurgical bond with substrate when compared with single layer PVD thin films. Multilayer PVD surface coating is a promising technique for deposition of thin MoS_2 films on sheet metal forming tool with excellent adhesion, non columnar microstructure and high hardness.

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