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Effect of Deposition Temperature on the Wear Behavior of WC-Co coated Mild Steel Substrate

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***Abstract*— Mild steel offers versatile properties at relatively lower cost. Therefore, the alloy has a large application base in the industry, nonetheless mild steel still possesses application limitations required by the increasing complexity and severity of service environments. Atomic-scale surface microstructure modification by rf magnetron sputtering deposition presents a technological solution to improve material properties and performance for a wide range of industrial applications. The focus of this work was to investigate and comment on the wear behavior of surface modified mild steel surfaces subjected to different deposition temperatures. The effect of deposition temperature on the surface morphology of the material is also reported and correlated to the wear performance. The results showed that resistance to dry sliding wear of mild steel increased with increasing deposition temperature as well as decreasing roughness.**

***Keywords*—mild steel; rf magnetron sputtering; wear perfomance**

I. Introduction

Mild steel is widely utilized in a vast number of engineering application such as construction, nuclear, mining and oil industries amongst many others. This is due to its low cost, good formability and excellent weldability [1]. Mild steel is a material of choice for a variety of engineering applications, but its properties present a setback for applications in extreme operating environments because it is lacking in the simultaneous wear resistance at the surface and tend to break easily upon impact during operations [2]. To improve such properties, surface modification techniques can be employed such that the application of the alloy is broadened.

Sputter deposition of tungsten carbide thin film on the mild steel surface is one of the surface modification method that shows prospect to improve the alloys wear performance and compressive strength to eliminate or minimize its limitations in industry. The WC thin film is opted due to its extreme hardness, good corrosion and wear performance [3-5].

The classification of different surface treatment and film deposition techniques are shown in Fig 1. The choice of the technique depends on the aims and objectives of the project.

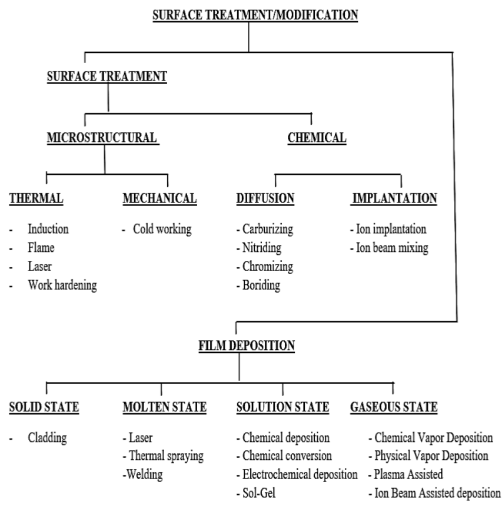

Fig 1. Classification of surface treatment and film deposition n techniques [6]

Sputter deposition is a thin film deposition method which is based upon ion bombardment of a source material (target) to transfer its atoms to the surface of the substrate material [7]. Film forming process parameters such as temperature and sputtering power have a substantial influence on the morphology, quality and properties of WC thin films. [8]. Previous study from Thomton et al [8] indicated that the changes in deposition temperatures directly affect the mobility of adatoms governing the structure evolution. Therefore, it is of great scientific and practical significance to study the effect of deposition parameters on film properties.

Wear is defined as the irreversible loss of interacting surfaces that induces gradual removal or deformation of solid surfaces [9], this surface deterioration eventually leads to material failure or loss of functionality and thus ultimately incur large and undesired economic losses. The combination of material hardness and strength plays a significant role in the wear performance of materials.

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The solemn purpose of this study is to specifically investigate the wear behavior of surface coated mild steel synthesized under various deposition temperatures.

II. METHODOLOGY

RF Magnetron sputtering was used to deposit WC-Co thin films onto five mild steel substrates varying temperatures 44°C,70°C,80°C,90°C and 110°C. Samples were then sectioned to 10mm x 5mm dimensions, ultrasonically cleaned in ethanol for 10 minutes and mounted in the Bruker contour GT profilometer to determine the roughness. Wear performance was investigated using a multifunctional tribometer (Rtec-instruments). The equipment can perform tribology test utilizing its inbuilt imaging modules such as interferometer, microscope and AFM spectrometer which was used to produce micrographs and surface profiles of the wear scar. The wear tests were conducted at room temperature under dry conditions. The wear test parameters used are shown in Table 1.

Table 1. Wear test parameters

Item	*Parameter*
Wear Test	Reciprocating, ball on block
Sliding velocity	2 mm/s
Normal Load/Force	10N
Lubrication	Unlubricated/Dry
Ball material	E52100 Alloy steel, grade 25
Ball size diameter	6.350mm
Stroke Length	5mm
Test Duration	5 minutes

III. RESULTS AND ANALYSIS

A. *Surface Roughness*

Three-dimensional visuals of surface roughness on different sample surfaces are presented in Fig 2 and the roughness properties of the film presented in Table 2. From the surface images, the increase in temperature decreases the surface roughness. This trend has been observed for several thin films and is attributed to the evolution of the microstructure in the structure zone model from zone 1 to zone T [10]. At lower temperatures there is low mobility of adatoms resulting in a rougher film consisting of voids in between tapered column film structure, as the temperature increases, adatom mobility and diffusion increases and coarsening occurs in the early stages of growth thereby forming a smoother crystallographic texture. Further increase beyond 110°C would result in the growth of columnar grains due to bulk diffusion and surface roughness would be expected to increase.

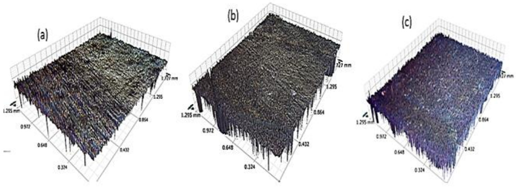

Fig 2. Three-dimensional images of surface roughness for samples deposited at substrate temperatures (a)70°C, (b)90°C and (c)110°C.

Table 2. WC thin film surface roughness properties

	Roughness Properties				
Sample	*Sa(nm)*	*Sku*	*Sp(nm)*	*Sq (nm)*	*Ssk*
44○°C	136.6±24	89.5±40	3808.2±549	201.1±23	1.2±1.9
70°C	263.2±31	22.6±4	4456.8±174	429.4±66	-2.5±0.9
80°C	204.1±54	62.5±25	4349.8±109	313.6±75	-2.23±0.5
90°C	252.2±21	5.8±0.1	4128±369	337.8±26	-0.26±0.1
110°C	310.4±2	5.49±0.3	4351.5±133	402.23±2	-0.124±0.09

B. *Tribological Perfomance*

The wear performance was investigated on the WC coated samples. The results of the coefficient of friction were shown in Fig 3. The results revealed that as the deposition temperature is increased, the coefficient of friction also increases. This implies that higher resistance to the sliding motion is experienced at elevated deposition temperatures as expected. Hence at higher temperatures there is an increase in film crystallinity. However, the fluctuations of friction coefficients observed at the top of the CoF curve in Fig 3, this is due to the debris influence as well as the continuous breakage and detachment of the hard tungsten carbide layer [11].

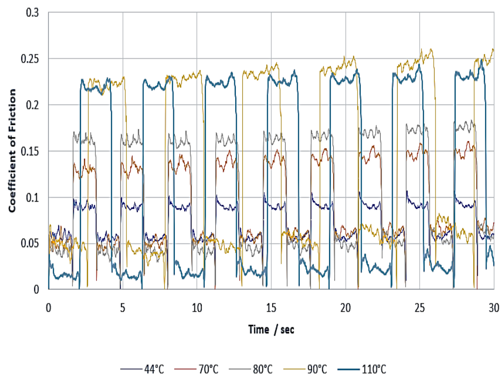

Fig 3. Influence of deposition temperature on the coefficient of friction.

The cross sections of the wear scar profiles are depicted in Fig 4 and their worn surface morphology presented in Fig 5 respectively. The profound ploughed grove observed implies prominent occurrence of abrasive wear. This is expected since the E52100 alloy steel ball used for the test is relatively harder

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than the mild steel substrate, the hard tungsten carbide thin coating eventually gets scrapped off during the test exposing the soft mild steel susceptible to ploughing. The surface profiles indicate improved wear performance with increase in temperature. The corresponding 3D images of the wear scar in Fig 5 also show decrease in wear degradation with increasing deposition temperature. This is attributed to the increased crystallite quality of the film due to higher adatom kinetic energy resulting in the formation of preferred growth orientation of the hard WC-Co thin coating on the surface of the mild steel substrate.

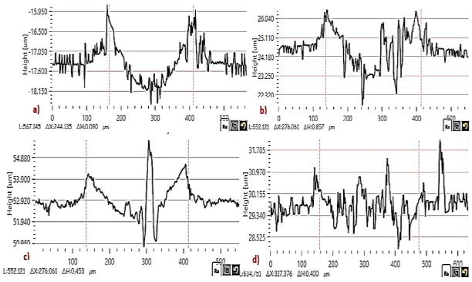

Fig 4. Cross-section of wear scar profile of the coated samples deposited at the temperatures of; (a) 44°C, (b)70°C, (c) 90°C and (d)110°C under constant 10N load.

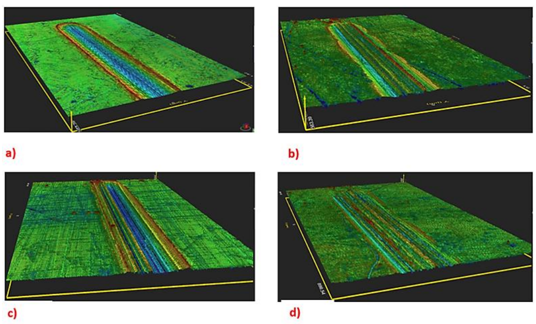

Fig 5. 3D images of coated samples wear scar for deposition temperature variation; (a) 44°C, (b)70°C, (c) 90°C and (d)110°C under constant 10N load.

Investigation was further extended to the volume loss of the film coating. It is thought that the amount of material volume loss on a surface (due to abrasion, erosion or other types of wear) can be used to describe the wear behavior of that material. The wear volume is extrapolated from the measure wear scar geometries and presented in Table 3 and Fig 6. The calculated wear volume decreases with increasing deposition temperature; however, the trend is not perfectly linear. The influence of impurities, the environmental conditions as well as the transformation of the material phases due to thermal effects during the test may be the cause of the observed offsets. The calculated wear volume is governed by the following equation [12];

$$V = \frac{\pi h}{6}\left[\frac{3}{4}d^2 + h^2\right],\ h = \frac{D}{2} - \frac{1}{2}[D^2 - d^2]^{1/2} \qquad (1)$$

Where V is the wear volume, h is the scar depth, D is the ball diameter and d is the wear scar width.

Table 3. Wear scar geometries for the determination of wear volume

Sample (Parameter)	*Wear Depth (μm)*	*Wear Width (μm)*	*Wear Volume (μm^3)*
WC 1 (44°C)	0.585	244.1	13694
WC 2 (70°C)	0.392	281.7	12221
WC 3 (80°C)	0.345	276.1	10332
WC 4 (90°C)	0.357	262.9	9694
WC 5 (110°C)	0.199	317.4	7876

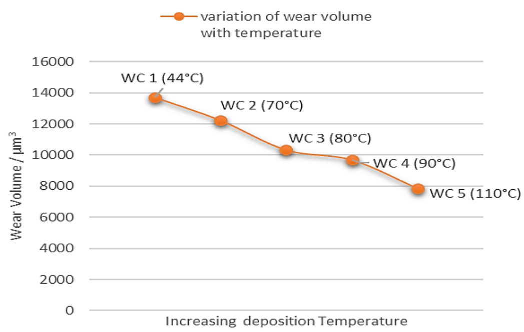

Fig 6. Effect of temperature on wear volume of the WC-Co thin film.

IV. Conclusion

The influence of deposition temperature on the surface topography and the wear behavior of tungsten carbide coated mild steel substrate was studied. The surface roughness of the alloy decreases with increasing temperature. better tribological performance is achieved by increasing the deposition temperatures, that is at higher deposition temperature the coated mild steel has a higher coefficient of friction and lower wear volume have more resistant to the sliding motion. The surface modification of mild steel through thin film deposition of tungsten carbide improves the material surface properties.

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