Preparation and characterization of TIG-alloyed hybrid composite coatings for high temperature solid lubrication

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ABSTRACT – There is an ongoing need in tribology community for developing high performance composite coating to control friction and wear under severe conditions of modern dry-sliding system which requires high operating temperature and long life. The present work is an attempt to employ powder preplacement and tungsten inert gas (TIG) torch melting technique to generate titanium carbide (TiC) based hybrid composite coating with the addition of hexagonal boron nitride(hBN) or Ni-coated hBN (Ni-P-hBN) lubricant powders. The morphology and composition of the developed coatings were investigated. Moreover, the hardness and high temperature wear characteristics of the hybrid coatings at 600^{o}C are studied. The results indicate that TIG-melted surfaces containing TiC and Ni-P-hBN exhibits optimum properties combining good control of microstructures and uniformly distributed hardness as well as stable tribological properties.

1. INTRODUCTION

In recent years, incorporation of finely dispersed hard ceramic phases on the metal surface layer by surface melting has been recognized as a promising method for the formation of quality surface coating. This revolutionary approach offers possibilities to change the chemical composition of the metal surface in order to achieve increase in surface hardness for tribological purpose [1]. Among many ceramic particulates, titanium carbide (TiC) particles are widely used to produce hard, wear resistant surface layers for a range of industrial application because of its high hardness, good thermal and chemical stability as well as lower density [2]. However, TiC-reinforced coatings exhibits challenges of low abrasive and adhesive wear resistance coupled with high coefficient of friction under applications requiring high-temperature and dry sliding conditions. To achieve reduction in the wear loss rate and friction, second phase of solid lubricant particles are thought to be added to the TiC coating matrix to produce a functional hybrid composite coating. The idea is reasonable and feasible owing to the synergetic combination of high-strength particle reinforcement and soft-particle lubrication in the hybrid coating system, results in coating with adequate lubricating properties for sliding process [3].

Hexagonal boron nitride (hBN) is a promising solid lubricant owing to its graphite-like lamellar crystal structure which allows lowered inter-layer sharing over a wide range of temperature. Up to now, hBN particles are, however, less explored for composite coatings due to their non-wettability with most ceramic/metal matrix [4]. Recent research made by Liu et al [4], indicated that encapsulation of h-BN lubricant with layer of active metal matrix such as nickel could be explored to improve the wettability performance of hBN. Therefore, in the present study, TiC powder was selected as matrix and hBN as solid lubricant, the hBN was incorporated in a layer of micro Ni-P deposit by electroless plating. The TiC/hBN and TiC/Ni-P-hBN hybrid composite coatings were developed on low alloy steel (LAS) using powder preplacement and TIG melting technique. Finally, surface topography and microstructures of the coatings were characterized in detail.

2. EXPERIMENTAL

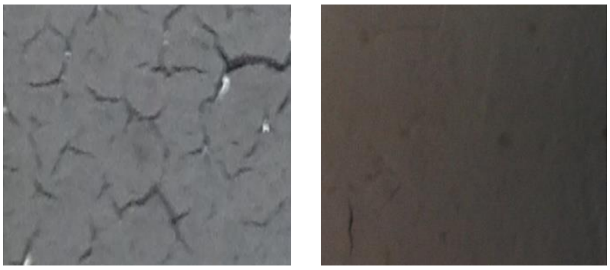
AISI 4340 low alloy steel (LAS) specimens were used as substrate material in this investigation. Prior to surface melting, the surface of the specimens were abrasively ground with SiC emery paper and then cleaned in acetone using ultrasonic cleaner. TiC powder (Sigma Aldrich, USA) was selected as the coating matrix material and hBN (MK Impex Canada) were used as the solid lubricant. A Ni-coated hBN (Ni-P-hBN) powders was synthesised by acidic electroless nickel plating bath.

The powder mixture was prepared by adding 10 wt% of hBN or Ni-P-hBN to TiC and ball-milled for producing TiC/hBN and TiC/EN-hBN composite powders. The blend was separately made into paste with binder and then evenly preplaced onto the substrate surface. Subsequently, surface melting of the precoated specimen was realized under TIG arc torch to generate track layers of TiC/hBN and TiC/EN-hBN coatings on the substrate material. The surface morphology, microstructure and composition were characterized with the aid of optical microscope (OPM), scanning electron microscope (SEM) and energy dispersive X-ray analysis (XRD) respectively. The cross-section microhardness and dry sliding wear test at 600^{o}C were conducted on Wolpert Vickers microhardness tester and DUCOM ball-on-disc tribometer (TR-20-PHM-CHM-600).

3. RESULTS AND DISCUSSION

3.1 *Visual Inspection of Powder preplaced Surfaces*

Fig. 1 shows the surface appearance of the precoated powder based on visual inspection under a high resolution camera.



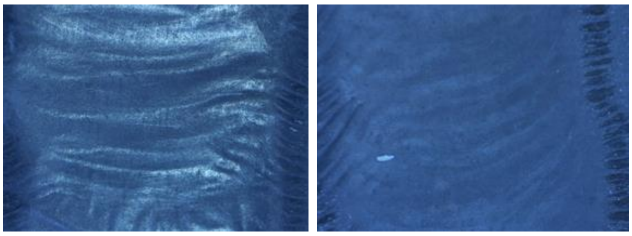
(a) (b)

Fig.1. Surface morphology of composite powder mixture (a) TiC/hBN (b) TiC/EN-hBN.

From Fig. 1a, addition of hBN powder damaged the flowability of the predeposited composite powder and led to their poor adherence to LAS substrate. This observation could be attributed to the poor wettability of *h*BN reinforcement. On the contrary, the preplaced steel surfaces obtained with TiC/EN-*h*BN mixture were found to be smooth with little or no discernible deformity as shown in Fig. 1(b).

3.2 *Surface Topography*

The TIG-melted surface produced with TiC/*h*BN composite powder revealed relatively rough topography; inconsistent rippling marks and few cracks were observed in the resolidified track (Fig. 2b). Fig. 2b showed the surface structure of TIC/Ni-P-hBN track revealing a fairly smooth surface, fine ripples and no visible cracks was observed on the surface.

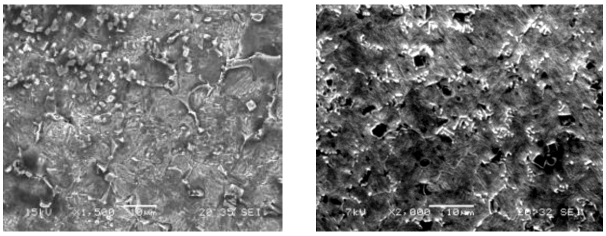


(a) (b)

Fig.2. SEM micrograph showing topography of the tracks (a) TiC/15% hBN (b) TiC/15% EN-hBN.

3.3 *Microstructure of the TIG-Modified Layers.*

The track alloyed with TiC/hBN composite powder produced a melt structure with partial dissolution of the powder mixture, presence of pores and cracks (Fig, 3a). The result is related to the poor flowability of the preplaced sample based on the presence of hBN in the coating.



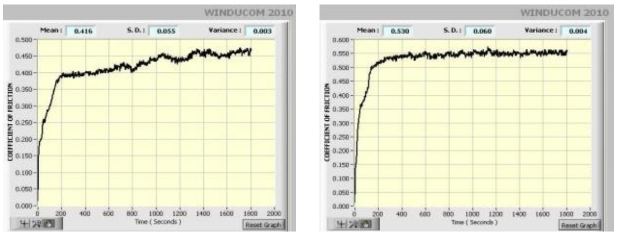
(a) (b)

Fig. 3. SEM micrograph showing melt structure of (a) TiC/*h*BN (b) TiC/EN-*h*BN.

As presented in Fig. 3b, TiC/Ni-P-hBN track produced a melt structure that had completely dissolved after melting and resolidified into dendritic and precipitated particles. This phenomenon indicates the effectiveness of adding electroless Ni-coated hBN which is thought to have allowed better physical interaction in the composite mixture leading to good melting.

3.4 *Dry Sliding Test*

It can be seen from Fig. 4a that TiC/hBN coating exhibits an unsteady high friction coefficient at the wear test of 600ºC. Fig. 4b shows that the friction coefficient of TiC/Ni-P-hBN is lower and remains stable at the elevated temperature. The results can be explained based on microstructure and elemental constitution.



(a) (b)

Fig.4. Friction coefficient of (a) TiC/hBN (b) TiC/Ni-P-hBN coatings at 600ºC.

4. SUMMARY

Based on the experimental findings, the following conclusion can be drawn;

a) Electroless Nickel plating was demonstrated to improve the wettability performance of hBN powder for composite coating.
b) The track of TiC/hBN coating showed microstructure containing mostly unmelted powder, pores and cracks probably due non-uniform melting of the weakly bonded preplaced surface. This was absent in the TiC/Ni-P-hBN coating which gave melt pool with mostly dendritic structure and carbide precipitates.
c) The high temperature tribological behavior of TiC/Ni-P-hBN is superior to that of TiC/hBN.

5. ACKNOWLEDGEMENT

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