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Wear mechanism and tribological characterization of novel nano-composite coated cutting tool material

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ABSTRACT – In recent years, there is a growing interest in the application of Nano-composite coating on the cutting tools to increase the wear resistance and high thermal stability. To reduce the friction and enhance the wear resistance, the hard Nano composites Yttria-Stabilized Zirconia (YSZ), Silicon carbide (SiC) and Aluminum oxide (Al_2O_3) show high performance capabilities. This article attributes a specific study of the application of YSZ, SiC and Al_2O_3 hard nanocomposite coatings which have been deposited on a carbide tool by electrostatic spray coating (ESC) technique. The coatings have been tested for wear and friction behavior by using a pin-on-disc tribological tester using a Ti-6Al-4V disc and hard nanocomposite coated carbide tool (pin) at ambient atmosphere. The electrostatic Nano-composite coated tools performed better and the outcome is expected to be useful in various industrial applications.

1. INTRODUCTION

For several decades, the refractory metal nitrides such as CrN and ZrN have been considered as hardening layers for cutting and forming tools due to their exceptional mechanical and tribological properties [1]. Hard nitride coatings were largely used in various types of cutting tools, which enhance the tool life, increase productivity and improve surface finish. [2]. Despite the fact of their outstanding properties, they were still inadequate for high temperature applications. During machining of titanium alloy, basic challenges such as high heat stress, variation of chip thickness, spring back, high pressure loads, residual stress and high machining costs were confronted. They acquire biological compatibility, excellent corrosion resistance, high strength to density ratio corresponding to other metals. However, their mechanical and chemical properties lead to poor machinability [3]. Titanium alloy is a poor conductor of heat, thus most of the heat produced by the cutting action is intensified on the tool rake (about only 50% of the heat developed is consumed into the tool when machining steel) [4], which in turn rises the temperature at the tool workpiece interface which affects the tool wear. Thus, in order to machine the Ti-6Al-4V alloy the tool material must have adequate hardness at high temperatures. Unfortunately, the increase in hardness is accomplished generally at the expense of strength and fracture toughness which makes the tool prone to chipping. To subdue these issues, an efficient approach is crucial for the successful application and sophistication of modern cutting process.

The current study emphasizes the role of coating the tool materials by means of Electrostatic Spray Coating (ESC) technique to enhance the cutting tool life. The friction behavior and wear mechanism were investigated by using the pin on disc tribological tester. The tungsten carbide pin (tool) was coated with nanostructured YSZ, SiC and Al_2O_3 thin film produced by ESC technique and the disc material being titanium alloy. In this article efforts have been made to perceive the effectiveness of the YSZ, SiC and Al_2O_3 coating on the tool wear. ASTM G99 standard pin on disc tribometer was used to perform tribological tests. Substantial resistance to wear on the pin was observed by the YSZ coating.

2. METHODOLOGY

2.1 Electrostatic spray coating (ESC)

Electrostatic spray coating is a process where nano particles are deposited electrostatically onto a conducting earthed substrate. The coating material (nano particles) were charged in a corona charger (nozzle) which is connected to a high voltage generation unit. The charged particles are transferred to the substrate which is under the influence of electrostatic force. The particles adhere to the substrate mainly due to coulomb attraction between the nano particles and the charges created on the substrate.

2.2 Dry sliding wear

Pin on disc tribometer was used to perform the dry sliding tests on Ti-6Al-4V alloy disc and tungsten carbide pin. The test was performed at ambient temperature with a relative humidity of 36%. For friction and wear test the following conditions were tested, as follows.

(a) Dry sliding of Titanium alloy disc specimen against uncoated tungsten carbide pin.
(b) Dry sliding of Titanium alloy disc specimen against YSZ, SiC and Al_2O_3 coated tungsten carbide pin.

Table 1. Experimental conditions

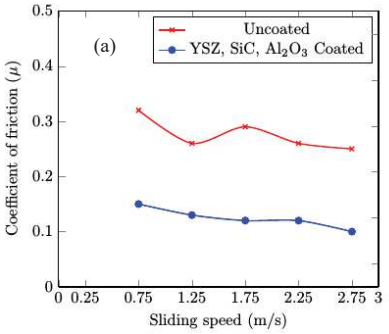
Process parameters	Value
Disc rotation speed [rpm]	500
Sliding speed [m/s]	0.75, 1.25, 1.75, 2.25, 2.75
Normal load [N]	20
Test duration [min]	30

3. RESULTS AND DISCUSSION

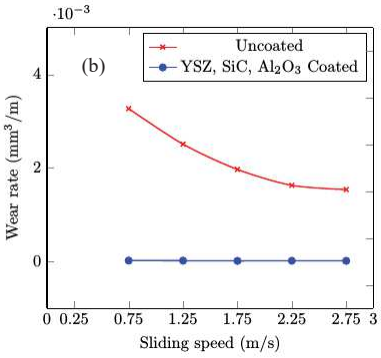
Tribological tests were conducted under two conditions (Coated and Uncoated) to investigate the performance of the ternary coating under dry sliding condition. In this study, frictional force, wear rate and temperature at contact interface were investigated. Notable reduction in the wear rate and frictional force

were observed during dry sliding contact interface with coated pin.

The impact of hard coating on the pin specimen under dry sliding condition and wear of the pin material were examined.



(a)



(b)

Figure 1 Tribological characteristics (a) Wear rate against sliding speed and (b) coefficient of friction against sliding speed.

Figure 1(a) depicts the results through various experimental conditions, it can be summarized that the uncoated pin specimen exhibited considerable adhesion and resulted in significant material removal. The lower wear rate with hard coating is possibly due to the brittle nature of the ceramic material. It is apparent from figure 1(b) that the introduction of hard nano composite coating significantly reduces the friction as the sliding speed and temperature increase. Increased sliding speed of coated pin probably promotes the resistance of wear and subsequently decreases the frictional force even at high temperatures.

4. CONCLUSION

The wear behavior of YSZ, SiC and Al_2O_3 coated tungsten carbide tool material subjected to dry sliding condition was investigated to analyze the effects of sliding speed. The results revealed that as the sliding speed increases the frictional force between the contact surfaces decreases and exhibited better surface finish in the presence of hard nano composite coating. The tungsten carbide tool material coated with YSZ, SiC and Al_2O_3, showed a good thermal shock resistance due to its low thermal conductivity and chemical inertness. The predominant wear mechanism transpired high wear in the absence of hard nano composite coating due to high adhesion and plastic deformation at the contact interface as the sliding speed increased. The wear mechanism for dry sliding along with hard nano coating on the tool material, which increases the tool persistence and estimate the operating conditions that ensure high performance both in machine elements and cutting tools.

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