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Adhesive wear performance of tungsten carbide based solid lubricant material

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ABSTRACT

In this work, adhesive wear performance of the developed tungsten carbide based solid lubricant material is presented. In-house developed materials were evaluated for the sliding wear performance against the commercial tungsten carbide disc. Removal of cobalt binder in the sintered material is identified as the major surface failure mechanism under adhesive wear condition. The formation of the transfer layer on the counter material during adhesive wear is confirmed with the aid of non-contact profiler. Soft phase calcium fluoride formed a bulky transfer layer on the counter disc which resulted in the reduction of friction and wear. In spite of similar frictional force, wear loss was found to be less when compared to that of abrasive condition. The measured net surface temperature of the test specimen also confirmed that tungsten carbide with calcium fluoride exhibited less friction. Wear tracks obtained after scratch resistance test confirmed that WC with 5% CaF_2 material exhibited shallow and wide wear track. However, tungsten carbide without calcium fluoride material exhibited deep and narrow wear track.

1. Introduction

Tungsten carbide based materials are preferred for cutting tool applications due to its superior hardness and transverse rupture strength. Many attempts were made to understand the performance under adhesive sliding performance of these classes of materials, since cutting tool interaction with the workpiece is analogous to the adhesive wear. A significant amount of the works has been carried out in the past to understand the effect of carbide content, cobalt content over friction and wear behavior.

Klaasen et al. [1] evaluated the adhesive wear performance of the tungsten carbide and titanium carbide materials by turning mild steel at low speed and sliding wear tests. With the increase in carbide content, wear resistance was found to increase. The increases in proof stress and hardness were identified as possible contributions. During sliding, cobalt binder was formed as tribofilms on the surface due to the extrusion of binder material. Okonkwo et al. [2] evaluated the sliding wear performance of low carbon steel against hardened tool steel at various temperatures. Profilometer measurement and scanning electron micrograph confirmed the material removal and deposition during adhesive wear. At lower temperature, the material was found to be deposited, whereas at higher temperature, the material was found to be removed. Kagnaya et al. [3] evaluated the sliding wear performance of WC–Co pins against AISI 1045 steel discs to understand the relationship between heat generation and wear. Friction coefficient and the measured surface temperature of the pin exhibited similar behavior with respect to the time.

Bonny et al. [4] investigated the tribological performance of WC–10 wt.% Co and WC–12 wt.% Co against WC–6 wt.% Co in the reciprocating test rig. The worn-out surface revealed various mechanisms including polishing of grains, adhesion of wear debris, surface binder removal, grain cracking, grain fragmenting and grain pull out under various loads and speeds. Removal of binder has been identified as the major failure mechanism while investigating the wear performance to understand the effect of the load and sliding speed. Pirso et al. [5] investigated the friction and wear performance of tungsten carbide with various amounts (6–20 wt.%) of cobalt against the steel disc in the block on disc test configuration. With the increase in binding material, wear resistance was found to be decreased due to the reduction of the bulk hardness. Removal of binder phase is predominantly observed as the primary failure mechanism. Cemented carbide with lower binder content generated more frictional heat due to its less thermal conductivity. Pirso et al. [6] evaluated the sliding wear performance of tungsten, titanium and chromium carbides against the steel disc. With the increase in binder contents (10–32%) frictional resistance of the tungsten carbide cermets was found to increase and the reason for this behavior was not presented. Tungsten carbide cermets with higher binder content generated less temperature due to its high thermal conductivity. Surface damage of the tungsten carbide cermets confirmed the boundary between carbide grains as the weakest link. Engqvist et al. [7] investigated the wear of tungsten carbide with different binders (0, 6 and 11 wt.%) against the same material under air and nitrogen environments. At

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severe loads (350 N, 3000 rpm), thinner tribofilms were developed when compared to those of mild tests (150 N and 1500 rpm). Test under nitrogen environment formed slightly better coverage than atmospheric environment. Binderless carbide formed thinner tribofilms which primarily consist of WO_3. Mild sliding in the air produced tribofilms which primarily consist of WC, whereas severe sliding in the air consists of WO_3.

Pazhanivel et al. [8] investigated the scratch resistance and wear resistance of carbon coated tungsten carbide inserts. Carbon coated WC insert exhibited the lower coefficient of friction than uncoated WC insert. Machined workpiece also exhibited superior surface finish when machined with carbon coated WC insert as compared to that of commercial WC insert. Barium and calcium fluorides were plasma sprayed over mild steel substrates [9] and evaluated for the friction wear performance. Stainless steel balls were slid against CaF_2 coated substrate discs at dry condition. Discontinuous tribo-reaction layers were observed on the worn-out surface of the coating. The worn-out surface of the coating revealed the abrasive wear as the primary failure.

Qiao et al. [10] included calcium and barium fluoride with tungsten and aluminum to develop a composite for the cutting tool application. Developed materials were evaluated for friction and wear by reciprocating it against commercial silicon carbide ball. Calcium and fluoride composites exhibited less friction. The worn-out surface of the fluoride composite revealed the adhesion wear as the predominant wear. Bolton and Gant [11] added solid lubricant, calcium fluoride, to high speed steels to improve wear properties and evaluated the phase reactions and chemical stability of the composites. Bolton and Gant [12] added solid lubricant, manganese sulfide, to high speed steels to reduce friction and improve wear resistance. Developed materials were evaluated for the three point bend strength and fracture toughness. Deng et al. [13] included calcium fluoride fillers to the aluminum oxide and evaluated the sliding wear performance. Developed materials were made into blocks and slid against the tungsten carbide disc. The worn-out surface of the developed materials without calcium fluoride revealed the abrasive wear as the primary wear mechanism. Material with calcium fluoride revealed the thin tribofilm on the worn-out surface. Muthuraja and Senthilvelan [14] evaluated the friction and wear performance of tungsten carbide based solid lubricant material against silicon carbide abrasive sheet. Due to the hard asperity interaction, failure was dominated by plowing rather than asperity deformation and adhesion.

From the above literature, it is observed that considerable amount of work has been done to understand the friction wear behavior of cutting tool materials. Few works have been carried to understand the effect of carbide and cobalt contents over the tribological performance. Few works have been carried out by adding solid lubricant as coating as well as fillers and evaluated them for the friction and wear performance. No work has been attempted to understand the adhesive wear performance of tungsten carbide based solid lubricant material and this work attempts the same for the comprehensive understanding.

2. Experimental details

2.1. Materials and manufacturing

In this work, solid lubricant calcium fluoride (170–180 μm size, 98% purity, Loba Chemie) was used as a filler and added to the base cutting tool material, tungsten carbide (15–18 μm size, 99.8% purity, Rapicut Carbides). A fixed amount (10 wt.%) of cobalt (20–30 μm size, 99.5% purity, Loba Chemie) was used as binder. The various amounts of solid lubricants (0, 3, 5, 7 and 10 wt.%) were added to the WC to Co. These materials were milled in a planetary ball mill (Insmart, PBM07) under nitrogen (0.5 kg/cm^2) environment for 40 h. Plate speed and bowl speed were 90 and 207 rpm, respectively and powder to ball ratio was taken as 1:5 to avoid contamination. Later materials were uniaxially compacted to test specimens of ($40 \times 16 \times 5$ mm) and sintered in a tube furnace (Bysakh, Okay 70T7) under nitrogen environment (0.5 kg/cm^2) to avoid oxidation. During sintering, initially the specimens were heated to 400 °C at a rate of 2 °C/min to prevent crack formation and stearic acid was removed by maintaining for 60 min. Later specimens were heated up to 1200 °C at a rate of 5 °C/min and then to 1450 °C at a rate of 3 °C/min. After reaching 1450 °C, specimens were maintained for 60 min, and then cooled down to ambient temperature at a rate of 3 °C/min. Detailed methodology adopted for material development; evaluation of density, hardness, fracture toughness and transverse rupture strength of the cutting tool material with the various amounts of solid lubricants were reported elsewhere [15]. Table 1 summarizes the evaluated properties.

Table 1
Evaluated properties [15].

Developed cutting tool materials	Hardness (HRA)	Density (g/cm^3)	Transverse rupture strength (MPa)
WC–Co	82.34	12.294	969.2
WC–Co–3% CaF_2	82.2	11.4234	771.56
WC–Co–5% CaF_2	84.95	14.634	1501.47
WC–Co–7% CaF_2	84.15	12.9904	1258.93
WC–Co–10% CaF_2	82.25	10.911	552.55

2.2. Adhesive wear test

In this work, in-house developed tungsten carbide materials with various amounts of (0–10 wt.%) CaF_2 were made to slide against commercial WC–6% Co (Rapicut Carbides) in the pin on disc tribometer

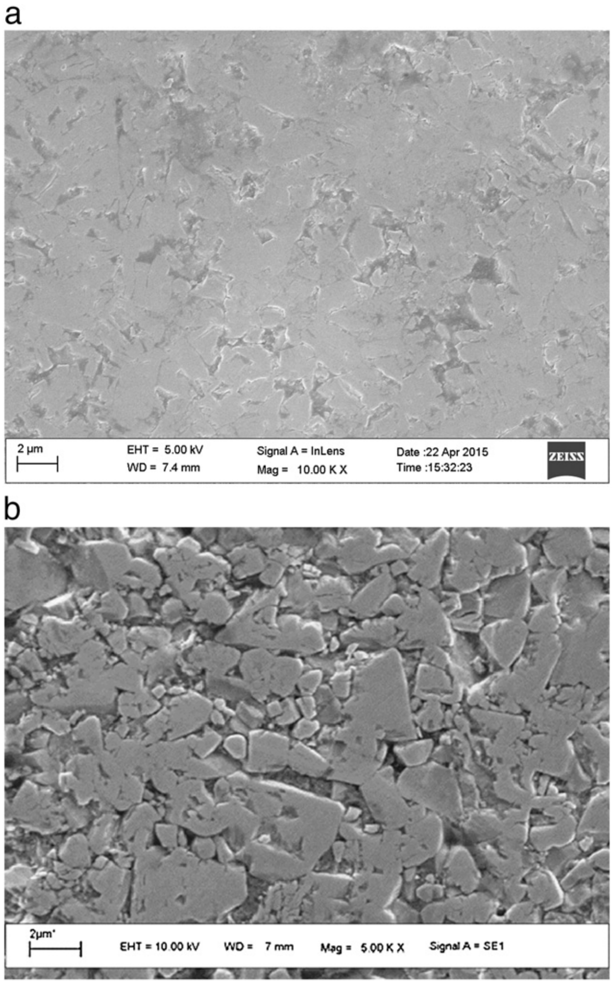

Fig. 1. a. Surface of the commercial WC–Co counter disc before testing. b. Surface of the developed WC–Co–5 wt.% CaF_2 test material before testing.