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Abrasive wear performance of tungsten carbide based self-lubricant cutting tool material

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ABSTRACT

The present study reported the friction and wear performance of the in-house developed tungsten carbide based solid lubricant materials. Calcium fluoride was used as a solid lubricant material and developed for the cutting tool application through ball milling, cold compaction and sintering process. Various amounts (0–10 wt.%) of calcium fluoride were considered and the friction wear performance was evaluated with the aid of the pin on disc test rig against abrasive sheet. Weight and surface roughness of the test specimens were measured before and after the test, in addition to the continuous measurement of frictional force and wear during the test. Worn-out test surfaces were observed under scanning electron microscope and three dimensional profiler to understand the wear mechanisms. The test material with 5 wt.% CaF_2 exhibited less friction and more wear resistance when compared to the other investigated materials. Energy dispersive X-ray analysis confirmed the presence of calcium and fluoride on the worn-out surface. Improved hardness and presence of lubricants in the developed material were found to reduce the friction and improve the wear resistance of material containing 5 wt.% CaF_2.

1. Introduction

Importance of dry machining has increased in recent years, since conventional cutting fluids are hazardous to the people and the environment. However, limited tool life and higher production times are some of the major limitations associated with the dry machining. Solid lubricant is identified as the potential solution for the above problem.

Deng et al. [1] developed Al_2O_3/TiC/CaF_2 cutting tool and evaluated the performance. Cutting and radial forces were measured at various cutting speeds and friction coefficient was computed. It was observed that the Al_2O_3/TiC/CaF_2 cutting tool exhibited superior performance compared to the Al_2O_3/TiC cutting tool. Deng et al. [2] evaluated the performance of Al_2O_3/TiB_2 cutting tool, wherein the oxidation product of TiB_2 acted as a lubricant. Friction coefficient was calculated with the measurement of cutting and radial forces at various cutting speeds. With the increase in cutting speed, friction was found to reduce due to the release of lubricant materials at higher cutting temperature. The cutting tool with higher TiB_2 content exhibited lower friction coefficient. Deng et al. [3] developed Al_2O_3/TiC/CaF_2 composites and evaluated the performance of the sliding wear with the aid of the block on ring test configuration. Material without CaF_2 exhibited significant surface damage and abrasive wear is identified as the dominant wear mechanism. However, the material reinforced with CaF_2 did not show any plowing grooves and scratches and confirmed the existence of thin CaF_2 film. Deng et al. [4] filled molybdenum di-sulfide in the microholes over the face and the flank surface of the cutting tool. The cutting tool filled with MoS_2 at the rake surface exhibited less friction coefficient compared to the cutting tool filled with MoS_2 at the flank surface as well as the conventional cutting tool. Bolton and Gant [5] investigated the addition of CaF_2 and MnS solid lubricant with high speed steel to develop a composite to improve wear properties. From the investigation (microstructure and XRD analysis) it is found that only slight wetting between the high speed steel and solid lubricant particle was found to have occurred.

Dhanasekaran and Gnanamoorthy [6] developed sintered steel (Fe–C–Cu) with solid lubricant, MoS_2 and examined the abrasive wear performance with the aid of the pin on disc configuration. Kagnaya et al. [7] investigated the wear performance of WC–Co cutting tool material with the aid of pin on disc configuration and measured surface temperature. Bonny et al. [8] evaluated the friction and wear behavior of WC–Co carbide with different (6–12 wt.%) cobalt concentrations with the aid of the reciprocating sliding wear tribometer. With the increase in load, a decrease in friction coefficient was observed due to the reduction of surface roughness. Deng and Cao [9] developed Al_2O_3/TiC with various amounts of CaF_2 solid lubricant and evaluated the tribological performance with the aid of the block on ring configuration. Jian and Dang [10] developed nickel based composites with graphite and molybdenum di-sulfide and evaluated its tribological performance. At room temperature, graphite contributed to the reduction of friction and MoS_2 contributed to the reduction of friction at higher temperature. Mixture of graphite and molybdenum sulfide contributes to the superior wear

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Table 1
Properties of developed cutting tool materials.

Test material	Hardness (HRA)	Density (kg/mm^3)	TRS (MPa)
WC–Co–0CaF_2	82.34 ± 3	12.3 ± 0.7	969 ± 48
WC–Co–3CaF_2	82.2 ± 2	11.4 ± 0.7	772 ± 39
WC–Co–5CaF_2	84.95 ± 2	14.6 ± 0.1	1502 ± 75
WC–Co–7CaF_2	84.15 ± 2	12.9 ± 0.9	1259 ± 63
WC–Co–10CaF_2	82.25 ± 2	10.9 ± 0.2	553 ± 28

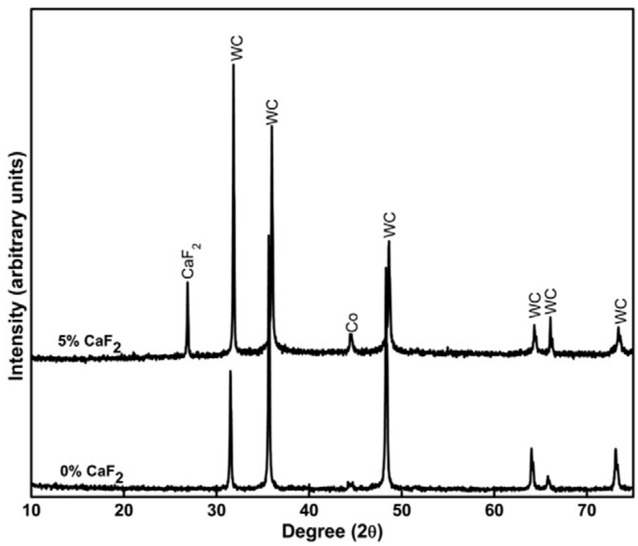

Fig. 1. X-ray diffraction of straight WC–Co and WC–Co–5 wt.% CaF_2 material.

resistance and reduced friction at a wide range of temperature. With the increase in MoS_2, coefficient of friction and wear rate was found to decrease.

Solid lubricants are applied either as surface coatings or as fillers in the self-lubricating composites. Most of the applications prefer surface coating rather than fillers, since they do not alter the core material properties. Some of the major desirable properties of the solid lubricant are low constant and controlled friction between two bearing surfaces, chemically stable over the required temperature range, ability to adhere strongly to one or both bearing surfaces, and resistance against wear, non-toxic and economical. Most of the materials are not able to satisfy all these requirements. Thus only few including graphite, molybdenum di-sulfide and polytetrafluoroethylene [11–16] are being considered. However, these materials are not suitable for machining application, where high temperature is involved. Hence CaF_2 is preferred for cutting tool application particularly as a filler in the composite [1–3].

From the prior works, it was observed that various solid lubricants, including calcium fluoride, molybdenum di-sulfide, titanium di-boride, tungsten di-sulfide, and graphite were used to reduce friction and wear of various composites. It is also observed that very few works have been carried out on the development of solid lubricant cutting tool material and there is a need to understand the tribological behavior of such solid lubricant cutting tool material. The main aim of the present work is to evaluate the tribological performance of the developed tungsten carbide based self-lubricant cutting tool material.

2. Materials and test conditions

Tungsten carbide, cobalt and calcium fluoride were chosen as base material, binder and solid lubricant, respectively for the development of solid lubricant cutting tool material. Tungsten carbide (WC) of

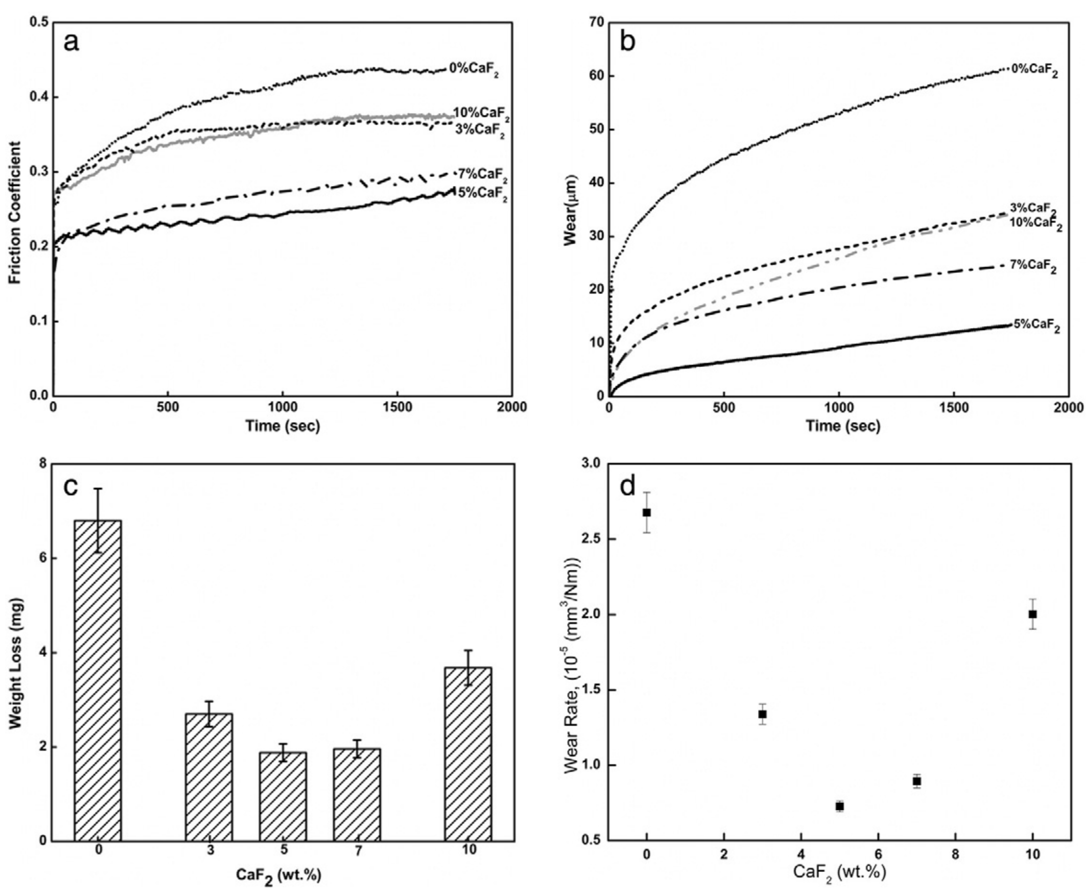

Fig. 2. a. Friction performance of the test material ($v = 0.5$ m/s, $F_N = 19.62$ N). b. Wear performance of the test material ($v = 0.5$ m/s, $F_N = 19.62$ N). c. Weight loss of the test material ($v = 0.5$ m/s, $F_N = 19.62$ N). d. Wear rate of the test material ($v = 0.5$ m/s, $F_N = 19.62$ N).