Materials Chemistry and Physics 198 (2017) 145–153

Contents lists available at ScienceDirect

Materials Chemistry and Physics

journal homepage: www.elsevier.com/locate/matchemphys

Tribological behavior of M50-MoS_2 self-lubricating composites from 150 to 450 °C

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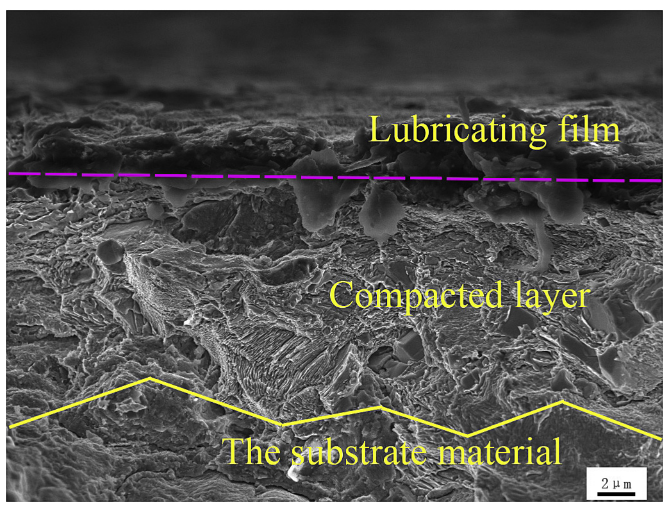
HIGHLIGHTS

- A new lubricating phase FeS was formed in MMC during SPS process.
- Lubricating structure consisted of lubricating film and underneath compacted layer.
- MoS_2 and FeS showed synergistic effect on improving tribological properties of MMC.
- MMC maintained a good lubrication performance over the wide temperature range.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 6 January 2017
Received in revised form
4 May 2017
Accepted 28 May 2017
Available online 29 May 2017

Keywords:
M50
Self-lubricating
FeS
MoS_2
Tribological behavior

ABSTRACT

M50 steel was widely applied to manufacture aircraft bearing whose service life was mainly determined by its tribological behavior. The primary purpose of this study was to investigate the tribological behavior of M50-5 wt%MoS_2 composites (MMC) sliding against Si_3N_4 balls from 150 to 450 °C at 20N-0.2 m/s. The results showed that the excellent tribological performance of MMC was obtained for the lower friction coefficient of 0.17–0.62 and the less wear rate of 1.9–3.5 × 10^{-6} $mm^3N^{-1}m^{-1}$ at 150–450 °C, which was attributed to the formed lubricating structure consisting of the lubricating film mainly containing massive MoS_2 and FeS, as well as underneath compacted layer. The enriched added MoS_2 and FeS generated during the sintering process in the lubricating film could provide good lubrication from 150 to 350 °C, while FeS for its excellent plastic flow capacity from 350 to 450 °C was well spread out on the friction surface to realize the lubricating role continuously, which made MMC maintain a long-lasting

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http://dx.doi.org/10.1016/j.matchemphys.2017.05.044

lubricating performance. The compacted layer played the role in supporting the lubricating film to prevent it from being damaged.

1. Introduction

M50 bearing steel was widely used in aircraft engines spindle bearings and high-temperature bearings due to its excellent high-temperature strength, thermal fatigue resistance, and thermal stability, while its work temperature was generally limited below 315 °C [1–3]. The tribological properties of M50 steel directly affected the service life and reliability of bearings, especially under high-temperature conditions [4–6]. Hence, it was significant to explore the tribological properties of M50 steel for improving the service life and reliability of aircraft bearings at different temperatures [7].

The effects of high temperature on the friction and wear characteristics of M50 steel had been investigated [8]. The research results [9] showed that the effects of temperature on friction and wear of M50 steel were significant. With the increasing of testing temperature from 20 to 400 °C, the frictional interface presented some metal film, and wear mechanism of material changed from microcutting to smearing and wear. Meanwhile, wear volume of material mainly depended on bear capacity of the surface film. Liu et al. [10] investigated the effect of critical temperature on friction and wear mechanism of M50 steel. The results showed that 400 °C was a critical temperature to cause change of friction and wear mechanism of M50 steel. Below 400 °C, wear volume of M50 steel increased with the increase of temperature and frictional coefficient almost kept at a constant level. Over 400 °C, wear volume decreased with the increase of temperature because of presentation of surface metal film. In recent years, the tribological properties of coated M50 were also reported. The tribological behavior of M50 micro coated with carbon composite coating was investigated by Pathak et al. [11]. The results showed that tungsten carbide coated M50 could be able to reduce the friction coefficient and wear rate compared to uncoated M50. However, it was well known that the coating could not achieve self-replenishment of the lubricating composites and had a shorter life. Studies [12,13] showed that the solid self-lubricating materials could achieve the migration of lubricants to maintain longer service life and had excellent lubricating performances under the conditions of high temperature, heavy load and high pressure. Hence, the research of M50 based self-lubricating materials had positive significance to the improving of tribological properties of aircraft bearings.

The layered solid lubricants, such as graphite, MoS_2 and Ti_3SiC_2, had been extensively added into self-lubricating composites for improving the friction and wear properties. Xu et al. [14] investigated the tribological properties of NiAl matrix composites containing graphite. The results indicated that the lubricating performance of graphite was not very excellent. Ti_3SiC_2 was the lubricant of high temperature (>500 °C) as stated and explained by Yang et al. [15], which could not be suitable for M50 aircraft bearing whose work temperature was generally limited below 315 °C.

MoS_2 had a good lubricating performance below 400 °C, which was a good choice for applications of M50 aircraft bearing that needed an adaptive and self-lubricating behavior. Mutyala et al. [16] investigated the influence of MoS_2 on the rolling contact performance of bearing steels in boundary lubrication. The results showed that effective lubrication had been achieved for employing MoS_2. Shi et al. [17] explored the effects of MoS_2 on tribological behavior of NiAl matrix composites. The results showed that MoS_2 played the main role of lubrication below 400 °C, and the tribological performance of NiAl matrix composites was excellent for the lower friction coefficient and less wear rate. Hence, the friction and wear mechanisms of MoS_2 with M50 steel need to be investigated. As well known, the best wear and friction behavior could only be attained at an optimum concentration of solid lubricant for a specified composite [18,19]. Too abundant quantity of solid lubricant would result in a remarkable decline in the mechanical property of the composite and in turn an increase in the wear rate and friction coefficient. In another unpublished work by the same authors, the different concentration of MoS_2 was investigated. Results obtained that the optimum level of lubrication was 5 wt% which was an appropriate level in consideration of the mechanical property of the composite. Moreover, the study temperature range was set at 150–450 °C according to the general working temperature of M50 aircraft bearing at about 300 °C.

In this paper, the tribological properties of M50-5 wt%MoS_2 composites (MMC) sliding against Si_3N_4 balls were investigated from 150 to 450 °C under the same condition of 20N load and 0.2 m/s sliding speed. In order to clarify the effect of the added MoS_2 and FeS formed during the sintering process on friction and wear at different temperatures, the morphologies of worn surfaces, cross section micro-structures of wear scars and corresponding element contents were analyzed. In addition, the wear mechanisms of MMC under different temperature conditions were also expounded.

2. Experiment details

2.1. Sample preparation

Experimental specimens were fabricated by powder metallurgy technique using spark plasma sintering (SPS). The composite powders of M50 matrix consisted of commercially available C, Mn, Si, Ni, Cr, Cu, Mo, V and Fe powders (30–50 μm in average size, 99.9 wt% in purity) by a mass ratio of 0.75C: 0.35Mn: 0.30Si: 0.20Ni: 4.0Cr: 0.15Cu: 4.2Mo: 1.0Mo: 89.05Fe (see Table 1) [2]. The weight fraction of MoS_2 in MMC was fixed at 5 wt%. Before SPS process, the raw powders were mixed by high energy ball-milling for 12 h with the milling speed of 200 rpm in vacuum. Balls and vials were made of hard alloy, and the charge ratio (ball to powder mass ratio) employed was 10:1. The mixtures were placed in a graphite mold with an inner diameter of 25 mm after being mixed and dried, and then put into the SPS machine with a D.R.Sinters SPS3.20 apparatus (Sumitomo Coal & Mining, now SPS Syntex Inc., Japan) to be sintered in a pure and protective Argon atmosphere at 1100 °C under a pressure of 25 MPa for 5min. The heating rate was 100 °C/min. In order to remove impurities formed on the surface, the as-prepared samples were mechanically ground and polished.

Table 1
Chemical compositions of M50 (wt%).

Composition	C	Mn	Si	Ni	Cr	Cu	Mo	V	Fe
Content	0.75	0.35	0.30	0.20	4.00	0.15	4.2	1.00	Balance