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Wear performance of bonded composite coatings under dry sliding

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ABSTRACT

In this study, epoxy bonded composite coatings were prepared by spraying process. The influence of Fe_3O_4 nano-particles and Ni–Zn–Cu ferrite particles as additives on the wear behavior of composite coatings was investigated. The wear behaviors of composite coatings were evaluated with a block-on-ring tribo-tester under dry sliding condition. The worn morphology of the composite coatings on the surface of counterpart steel ring was observed using scanning electron microscope (SEM). It was found that the wear resistance of the composite coatings was significantly improved when incorporated with Fe_3O_4 nano-particles, while less affected with Ni–Zn–Cu ferrite particles. The extreme pressure anti-wear characteristic of the composite coatings filled with magnetic nano-particle could be improved drastically, and the wear process of the composite coatings was predominantly caused by adhesive wear.

1. Introduction

Bonded solid lubricant coating is one of the main types of solid lubricant materials. As a result of exhibiting excellent anti-friction and wear-resistant properties, they are commonly used to solve tribological problems, especially those of lubrication in such applications where fluid lubricants are ineffective and undesirable [1–4]. Three coatings including graphite, molybdenum disulfide (MoS_2) and tungsten disulfide (WS_2) are commonly regarded as the most typical solid lubricant coatings in industries. Graphite as a solid lubricant is widely used because of the low cost and excellent lubricating performance, as a result, the lubrication roles of graphite were extensively investigated and entirely understood. Due to the presence of absorbed polar molecules for grapheme plane intercalation, lubricating efficiency of graphite appears, as water molecular intercalation occurs between basal planes, breaking weak π-electron bonding and allowing for easy basal plane shear, and therefore graphite is a good lubricant in moist environment [5–8]. Cenna et al. [9] researched the effect of the graphite particles upon the abrasive wear mechanism exhibited by polymer surfaces, the embedded graphite particles can act as a lubricant during abrasion process and reduce the wear rate. Pan et al. [10] designed a series of coatings with graphite and epoxy resin. At 50% content of graphite, an optimal solid lubricant coating which had the lowest friction coefficient and wear rate was obtained. Budna et al. [11] reported that graphite revealed synergistic effects with MoS_2 in improving the wear life of the bonded coatings.

Fe_3O_4 nano-particles could improve the tribological properties of the NBR (nitrile butadiene rubber) and promote the formation of MoS_2 transfer film on the steel surface [12,13]. Fe_2C matrix can be found in the auto-restoration layer [14]. Both Fe_3O_4 and $MnZnFe_2O_4$ nano-particles are capable of improving the wear-resistance and the load-carrying capability of the base oil, self-healing the worn steel surface by forming tribo-self-repair film on the sliding surface [15,16]. However, few works have been reported on the solid lubricant coatings filled with magnetic oxide.

The magnetization of the friction surface is related to the surface damage resulting from the transfer. This is due to the formation of transfer particles and wear particles and to changes in the magnetic-domain structure inside the material as a result of tribological action. The transferred particles can magnetize mainly in one direction by tribological action, showing that those particles on the friction surface are the principal source of tribo-magnetization of the friction surface [17–19]. The tribo-magnetization by tribological action helps to improve the wear-resistance of the coatings in which magnetic particles are filled. In this study, a series of bonded composite coatings were prepared, epoxy resin cured with the phenolic amine agent was chosen as the coating matrix. The authors had made an attempt to identify a set of potentially viable candidate bonded solid coatings containing solid lubricants, with or without magnetic oxide such as Fe_3O_4 and Ni–Cu–Zn ferrite. The effect of magnetic oxide on the wear-resistant properties of epoxy-bonded composite coatings in dry sliding condition was investigated and the corresponding wear mechanisms were discussed.

2. Experimental

2.1. Materials

Epoxy resin (E-44) and phenolic amine agent were used as binder and curing agent, respectively, and the silicon coupling agent (KH-550) was used to improve the strength of the coatings. Of the four solid lubricants, MoS_2, WS_2 and graphite powders were less than

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Table 1
Nominal epoxy coatings filled with different solid lubricants in wt.%.

Content (wt.%)	Specimens								
	G	G + N	G + F	G1 + M4	G1 + M4 + F	G4 + M1	G4 + M1 + F	G4 + W1	G4 + W1 + F
Graphite	60	60	60	12	12	48	48	48	48
MoS_2	0	0	0	48	48	12	12	0	0
WS_2	0	0	0	0	0	0	0	12	12
NiCuZn ferrite	0	4	0	0	0	0	0	0	0
Fe_3O_4	0	0	4	0	4	0	4	0	4

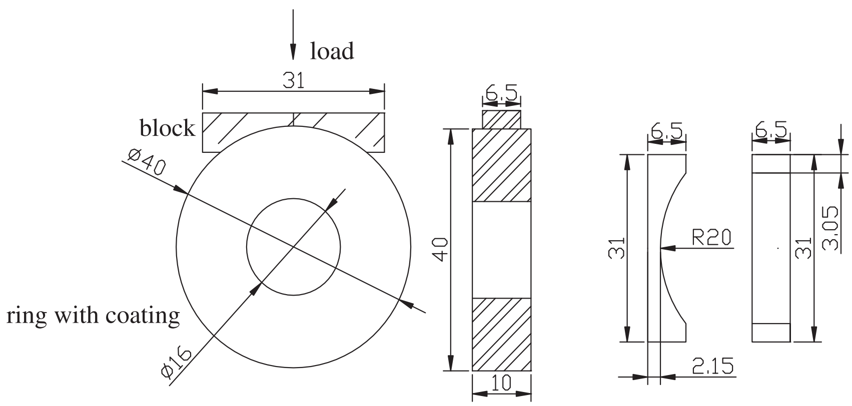

Fig. 1. Schematic diagrams of a frictional couple during dry sliding test.

5 μm in diameter and the PTFE micro-powders were in a diameter of approximately 3–4 μm. The Ni–Cu–Zn ferrite (<5 μm) and Fe_3O_4 nano-particles were used as fillers. The mixed ethanol/acetone/cyclohexanone in a volume fraction of 1:8:1 was employed as solvent. All chemicals were analytical reagent grade and used as received.

2.2. Preparation of the solid lubricant coatings

The preparation of the composite coatings are as following: First, the graphite with or without MoS_2 particles was mixed with silicon coupling agent (KH-550) in a ball mill, the quantity of the solid lubricants and the magnetic particles were 60 wt.% and 4 wt.% of the epoxy resin, respectively, as is shown in Table 1. Second, the mixed powders

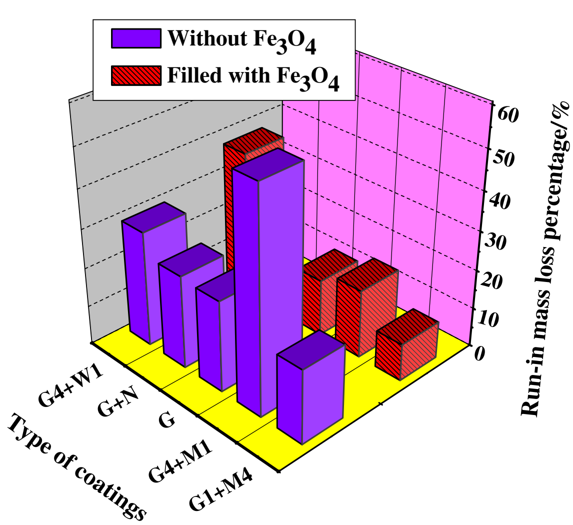

Fig. 2. Run-in mass loss percentage of the solid lubricant coatings filled with or without Fe_3O_4.

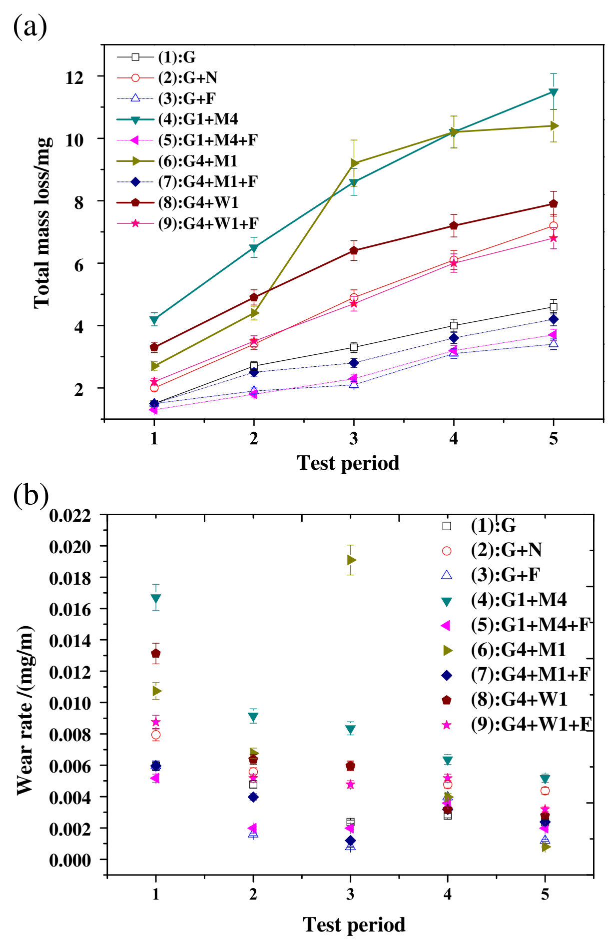

Fig. 3. Total mass loss (a) and wear rate (b) of the solid lubricant composite coatings.