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Tribological studies of soft and hard alternated composite coatings with different layer thicknesses

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ABSTRACT

In order to study the potential tribology using of composite coatings in which soft and hard layers are alternated, three common self-lubricating and anti-wear materials are deposited on bearing material matrix. Coatings with three different thicknesses are engineered to contain alternated layers of MoS_2, WC and Cu. They are tested by different contact loads and sliding velocities. The damage and failure of composite coatings are analyzed by finite element analysis. Results show that loads and velocities have significant effects on coating frictional properties. The soft layer decrease frictional coefficients, and the hard layer bear heavy loads. Frictional coefficients can be adjusted by loads, velocities and coating thicknesses. The matrix is protected effectively by alternated coatings.

1. Introduction

With the wide requirements of excellent mechanical frictional properties, coating technologies are commonly used in aerospace, marine equipment and some other important industrial fields. Nonetheless, various requirements usually could not be satisfied by single coating, such as single MoS_2 (Molybdenum sulfide) coating and WC (Tungsten Carbide) coating. MoS_2 is well known for its self-lubricating and low friction coefficients, but performance of anti-abrasion is poor [1]. WC is a hard material with high wear resistance, but its CoF (coefficient of friction) is high [2,3]. To satisfy both self-lubricating and anti-wear functions, some new compounds were synthesized and deposited on matrix. These rare materials not only were expensive but also complex to synthesize [4–6]. Thus, composite coatings were mostly applied to solve above problems because they had advantages of multiple single coatings. The frictional properties vary with coating thicknesses, contact loads and sliding velocities. However, materials properties of coatings had been paid much attention, but influences of coating thicknesses were neglected mostly [7–9]. Some other studies just focused on tribology properties of single coating thickness [10–12]. However, shear actions, load capacities and mechanisms vary with soft and hard coatings. What's more, the frictional properties of soft and hard alternated composite coatings had not been studied before, especially under different loads and sliding velocities. The stress distribution, crack generation and local thermal rise are the three indexes of coating properties. Coating damage can be analyzed by stress distribution and crack generation. Temperature rise and frictional mechanisms can be explained further by local thermal generation analysis. However, they few had been studied because the variations of stress, crack generation and thermal rise are difficult to experiment when frictional pairs are working at the same time. In this paper, soft and hard alternated composite coatings are formed by three common materials. Frictional properties of the composite coatings are studied by frictional tests and finite element simulation results. These alternated composite coatings are discussed by influence factors such as coating thicknesses, contact loads and sliding velocities. The frictional properties and influences of coating thickness of alternated composite coatings are depicted by equivalent stress, crack generation and thermal rise. The functions and mechanisms of soft and hard coating are illustrated. Through analyzing of load, velocities and thickness, the practical application is suggested.

2. Experiment

2.1. Material selection

Single coating loses its efficacy mainly due to crack rapid penetration and expansion [13,14]. However, the expansion and penetration can be slow down and avoided by layer buffer actions of multiple coatings. In addition, even if holes and cracks exist during the formation process, the next coating layer can fill in and improve the performances of all coatings. To study frictional properties of soft and hard alternated composite coatings, three coating materials have been used. Different with some new materials which were rare and hard to

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synthesize, the composite coatings are formed by common materials of Cu, WC and MoS_2. The reasons are as following.

Material of C96900 alloy is applied as coating matrix which is used for bearings. Its thermal expansion coefficient is $16E10^{-6}$/°C. Cu was commonly used as a solid self-lubricating material [15–17]. Its thermal expansion coefficient is $17E10^{-6}$/°C, which is close to that of the matrix material. Cu is a soft metal, and the soft coating is deposited on hard matrix which can wrap up hard abrasive grains. With frictional movement working, the self-lubricated films are formed [18]. The shortages of Cu are obviously such as small shear strength, poor anti-abrasion and low load capacity. However, WC had well anti wear and tear properties which were shown in many studies [19,20]. WC coating has excellent load capacity because its hardness is very high. Then the double coatings have been formed. The outside coating is WC, and the internal coating is Cu. Transfer films which generate from soft coating can encase hard debris of WC. It can repair the cracks and holes. MoS_2 is a common soft solid self-lubricating material. Due to the low friction coefficient, MoS_2 is widely used in many industrial applications. Combing with WC coating, both MoS_2 and WC coating can provide the best tribological properties.

2.2. Thermal spraying

Comparing with physical vapor deposition technologies, thermal spraying technology is efficient and low cost. By thermal spraying, MoS_2, WC and Cu powders can be deposited on matrix. Firstly, blasting treatment is performed on the surface of C96900 alloy matrix. Then it is cleaned by ultrasonic concussion with alcohol. Deoil of matrix surface and bonding force are cleaned and improved by this step.

Cu powder is 20 μm, and it is firstly deposited by thermal spraying. The spraying distance is 200 mm, and gun movement speed is 120 mm/s. Thermal stress can be decreased and bonding force improved by preheating treatment which temperature is 150 ± 20 °C. WC powder is 50 μm, and it is deposited after Cu. Its spraying distance is 180 mm, and gun movement speed is 180 mm/s. MoS_2 structure is laminated which is not easy sprayed. The original MoS_2 powder is 100 nm, and its purity is 99.9%. The nano-particles need to be agglomerated, granulated, and ground. By those steps the 100 μm particles are selected by 250 mesh sifter. The MoS_2 spraying distance is 200 mm, and gun movement speed is 150 mm/s. Cu, WC and MoS_2 coatings are deposited on the matrix successively which all by thermal spraying. Three different coating thicknesses have been made, which are 50 μm, 100 μm and 300 μm.

2.3. Frictional experiments

Tribological properties of coatings are influenced by two main factors which are contact load and sliding velocity [21–24]. Soft and hard coatings are defined based on their hardness and modulus of elasticity. Thus, Cu and MoS_2 coatings can be defined as soft coatings. WC can be defined as hard coating. Thickness of 50 μm, 100 μm and 300 μm can be defined as T50, T100 and T300 for convenient. The tribology experiments have been done using of UTM-2(CETR) friction and wear test equipment. Three different loads and velocities have been applied for T50, T100 and T300 in the frictional tests. Three different experimental variables were commonly applied in many studies, though more test conditions and times would lead to more clear results [25–27]. The loads and velocities are listed in Table 1. There are five experiment test conditions which are 5 N-10 mm/s, 10 N-10 mm/s, 20 N-10 mm/s, 10 N-15 mm/s and 10 N-20 mm/s. They are defined as P1, P2, P3, P4 and P5 successively. All frictional tests are done in dry condition because the matrix works in a dry frictional condition. Experiments of each sample are tested for three times. The stainless steel ball (304) is used as frictional pair. The frictional pairs, working time, frictional distance and all other test conditions are listed in Table 2. The CoFs of sample T50, T100 and T300 are shown in Fig. 1, Fig. 2 and Fig. 3.

Table 1
Different loads and velocities for frictional tests.

Layer thickness	T50	T100	T300
Loads	P1	P1	P1
	P2	P2	P2
and	P3	P3	P3
	P4	P4	P4
Velocities	P5	P5	P5

Table 2
Frictional test details.

Frictional Pair	Working time	Frictional distance	Load
∅5 mm stainless steel ball (304)	10 min	5 mm	Table 1
Velocity Table 1	**Test environment** room temperature	**Working condition** dry	**Test times** 3

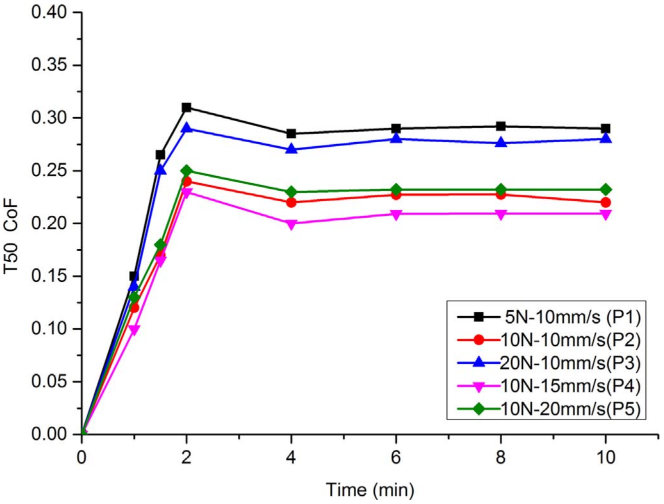

Fig. 1. CoFs of coating thickness is 50 μm.

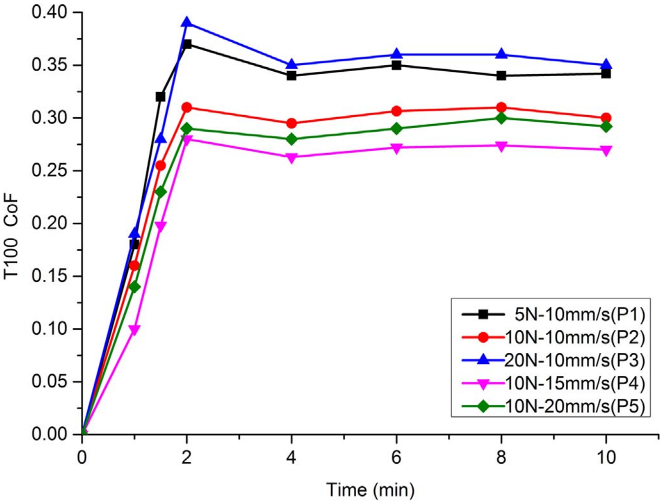

Fig. 2. CoFs of coating thickness is 100 μm.

2.4. Equivalent stress analysis

Equivalent stress is an evaluation criterion to analyze coating damage and failure. The frictional test results are the input parameters of simulation. Different loads and sliding velocities will lead to different