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A study of the frictional characteristics of metal and ceramic counterfaces against electro-deposited coatings for use on automotive seat rails

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ABSTRACT

An investigation was conducted on the friction coefficient changes when ceramic balls oscillate against a series of epoxy-based cathodic electro-deposited coatings that could be used for automotive components. Reciprocating sliding tests were conducted using ball-on-plate apparatus; balls were made of silicon nitride, zirconia, and AISI 52100 (also known as GB GCr15, DIN 100Cr6, and JIS SUJ2) steel. Plates used for coating substrates were made of cold-reduced high strength steels. The Coulomb friction coefficient was measured under room temperature and ambient humidity. The endurance lives of cathodic electro-deposited coatings against various ball materials are directly compared using a plot of friction coefficient evolution. Using the basis of friction coefficient evolution, electro-deposited coatings maintained higher durability against zirconia than against Si_3N_4 and AISI 52100 balls. In addition, the frictional behavior is analyzed using a form of Kachanov-type damage law. It is concluded that the growth rate of the friction coefficient can be represented by the damage parameters in the law.

1. Introduction

Electro-deposited coatings are popularly used for automotive components due to numerous advantages including low cost, fast deposition, corrosion resistance, and environmental friendliness [1]. Particularly, epoxy-based cathodic electro-deposited coatings are taken into account in an automotive seat sliding rail system. In a seat sliding rail system, metallic solid cylinders or balls located between the upper and the lower rails are used to enable reciprocal linear movement of the upper rail. A cylinder or a ball is subjected to tractive rolling on a rail. Unpredictably, gross sliding friction is arisen from the presence of dust or the third particle at the contact surface or in a retainer. Epoxy-based cathodic electro-deposited coating on the rail plays a role in reducing friction, resisting corrosion, and preventing squeak noise.

For the purpose of minimizing friction and squeak noise on a coated rail, various balls needs to be considered as the alternative to AISI 52100 steel balls. Particularly, ceramic balls are known as good choice for low friction and anti-squeak noise. Tribological performance of ceramic balls in a variety of working environments is reported in the literature [2–10]. Dry friction tests with silicon carbide and silicon nitride were conducted using ball-on-plate contact configuration [2]. Friction coefficient values of silicon carbide and silicon nitride against metals were determined under various humidity and oxide film conditions. Friction and wear of ceramics at pin-on-disk sliding contact were investigated [3]. Friction coefficient and wear of oxide ceramics and silicon-based ceramics were determined against ceramics and nickel-based turbine alloys. Friction behavior of ceramic-hardened steel couples was investigated under reciprocal sliding motion [4]. Friction coefficient evolutions of ceramic composites were evaluated at dry condition. Lubricated and unlubricated fretting wear behavior of silicon nitride was investigated with bearing steel (AISI 52100) counterparts [5]. Wear volumes of silicon nitride balls and of steel plates were measured at various fretting amplitudes. Friction and wear of silicon nitride-based ceramics against stainless steel 316 were studied with reciprocal ball-on-flat tests [6]. SiAlON ceramics were tested with different lubricants. Static and kinetic friction ceramic–ceramic and ceramic–steel pairs were determined under unlubricated and oil lubricated conditions [7]. Transition from static to kinetic friction of alumina was identified on a friction force evolution. Friction coefficient evolutions of ceramic balls including zirconia, alumina, silicon carbide and silicon nitride on zirconia disks were measured and evaluated [8]. Friction coefficient evolutions of alumina and zirconia ceramics against steel were compared [9]. It was identified that zirconia presented less friction coefficient than alumina under water lubricated conditions. Kinetic friction coefficient values of unlubricated ceramics

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sliding on itself at room temperature were reported [10]. Experimental results described above show that kinetic friction coefficient is various according to the sort of contacting material and test condition. Despite numerous experimental results about ceramics, little is found on kinetic friction coefficient evolutions of ceramic balls on electro-deposition coatings.

Friction coefficient of a solid lubricant coating evolves from a low value to a certain critical one while a coating on a substrate is being worn off. In order to understand friction behavior of a coating and to predict its durability, a friction coefficient evolution needs to be characterized.

Friction coefficient evolutions of various dry lubricant coatings under unidirectional sliding condition were described with exponential, linear, and logarithmic forms [11]. It was identified that friction coefficient growth rate of a coating can be expressed with two parameters. In order to evaluate coating deterioration during fretting cycles, fretting tests were interrupted and worn surfaces were analyzed [12]. The correlation between damaged area fraction and the friction coefficient was determined. However, friction coefficient growth rate of an electro-deposited coating under reciprocal linear sliding motion has not been described with an appropriate mathematical form.

In this study, the friction coefficient behavior of ceramic balls on epoxy-based cathodic electro-deposited coatings was investigated. Ball-on-plate friction tests are conducted under gross reciprocal sliding conditions. Measured friction coefficient evolutions are compared and described with a form of Kachanov-type damage law.

2. Experimental setup

2.1. Experimental rig

Fig. 1 provides diagrammatic depiction of the side view of the reciprocal sliding test machine. The test machine consists of a 1.25 kN load cell, a linear stage, a rigid arm, dead weight, a cylindrical ball holder, and a laser displacement sensor. For each test, a single ball and a flat specimen were used. A ball holder, made of mild steel, gripped a ball by a screw bolt and transferred a normal force to the contact surface of a flat specimen. A ball holder was permitted to vertical movement in the rigid arm. The clearance between a cylindrical ball holder and a hole in the arm was designed to be about 0.013 mm. A flat specimen was fixed on a carriage of a linear stage (PImiCos GmbH, LS-110) allowing horizontal reciprocating motion within the travel range of 26 mm. A laser displacement sensor (Keyence, LK-081) measured the displacement of the carriage with a resolution of 0.003 mm and a linearity of ±0.1%. A load cell connected to the rigid arm was used to measure frictional force arising from the contact between a ball and a specimen. The frictional force and the displacement measured by a laser displacement sensor were recorded. Coulomb friction coefficient was then computed as the ratio of a maximum frictional force to the force induced by dead weights after each cycle.

2.2. Materials and test conditions

The substrate of a flat specimen was made of cold-reduced high strength steel (SPFC 780DP). A coating was deposited on the substrate by a conventional cathodic electro-deposited process. Initial coating thickness on a flat specimen ranged from 0.02 to 0.03 mm. Three kinds of balls were selected with a diameter of 4.76 mm. The conventional ball used in an automotive seat sliding rail system is made of AISI 52100 (GB GCr15, DIN 100Cr6, and JIS SUJ2) steel. In this study, zirconia (ZrO_2) and silicon nitride (Si_3N_4) balls were selected with the arithmetic average surface roughness (R_a) of 0.025 μm. Table 1 shows the chemical composition of zirconia (ZrO_2) and silicon nitride (Si_3N_4) balls selected for reciprocal sliding testing. The chemical composition of commercial AISI 52100 balls is shown in Table 2 and mechanical properties of the balls are presented in Appendix A.

In this study, a normal force of 49 N was applied to the contact surface between a ball and a flat specimen. It was assumed that each ball on a seat sliding rail was subjected to 49 N in a loaded case (the loaded weight of a single seat was assumed as 80 kgf and the seat consisted of two sliding rails with 16 balls and without cylindrical rollers). The nominal displacement of a flat specimen was 1 mm and the specimen motion was imposed at a frequency of 1 Hz. Actual sliding distance on a seat rail is various, but a unit distance (i.e. 1 mm) was considered in this study. The displacement of 1 mm was sufficient for inducing gross slip at the contact. All tests were conducted at room temperature condition.

3. Results and discussion

Reciprocal sliding tests were conducted with uncoated specimens prior to those with electro-deposited coatings. Uncoated specimens were prepared by polishing the surfaces of cold-reduced high

Table 1
Chemical composition (wt %) of commercial ceramic balls.

Ceramic	ZrO_2	Y_2O_3	Si_3N_4	Y	Al	Ti
ZrO_2	94.8	5.2				
Si_3N_4			90.0–92.5	3.0–4.0	3.5–4.5	1.0–1.5

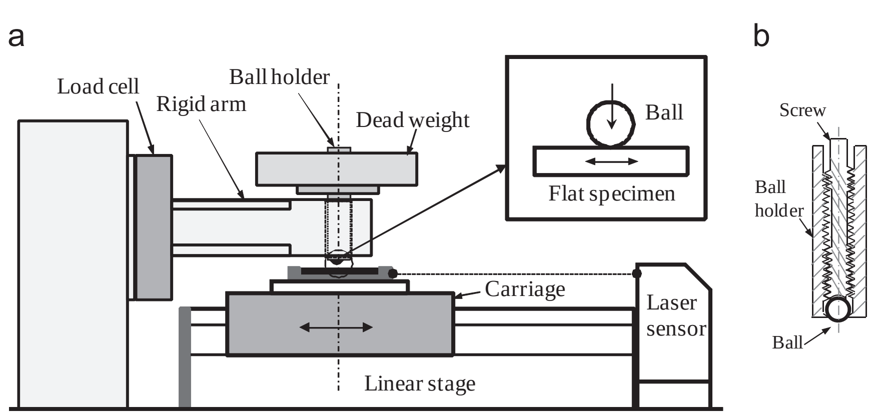

Fig. 1. Schematic illustration of the apparatus for reciprocal sliding testing: (a) testing machine, and (b) a ball holder with a screw.