EFFECTIVENESS OF TRANSFER FILM LUBRICATION FOR CERAMIC PAIRS IN SLIDING CONTACT AT 800ºC IN VACUUM

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ABSTRACT

Effectiveness of transfer film lubrication was examined in high-temperature vacuum in sliding friction tests. All the tested ceramic materials showed poor wear resistance and high friction when rubbed without lubrication. By forming a transfer film from a self-lubricating composite, dramatic improvement in wear resistance and decrease in friction was observed. Even when the transfer film was formed in air at room temperature, almost no wear was observed, although friction became high in a relatively short time. It is demonstrated that transfer film lubrication is promising for high temperature applications in vacuum.

1. Introduction

In re-usable space vehicles, some moving mechanical components, such as hinges, spherical bearings, air seals of aerodynamic control surfaces (flaps), will be required to operate at high temperature during re-entry to the Earth. In "hot structure" design concept, i.e. without thermal protection system (TPS), the operating temperature was estimated to be as high as 1600 ºC. Even when TPS is employed, the temperature will be 400 - 1000 ºC.

Woydt et al. [1] assessed some candidate lubrication mechanisms for tribo-systems operating at high temperature, and proposed promising substrate /coating systems for the hot hinge joints of re-usable vehicles. The development works of the hot hinge joints based on the assessment have been reported [2,3], and poor wear-resistance was pointed out as a problem. The experiments were carried out in air, and thus oxidation problem seems to be more serious than in low vacuum, in such conditions the actual hot hinge joints of re-usable vehicles will be operated.

In ultra-high vacuum, it has been reported that long-term operation was possible by utilizing transfer film lubrication for Si_3N_4 ball bearings at temperatures up to 650ºC [4], and for Si_3N_4/Si_3N_4 roll/slide friction tests at 750ºC [5]. These results confirm that transfer film lubrication is a promising lubrication concept for tribo-systems in high-temperature vacuum.

In this paper, effectiveness of transfer film lubrication is demonstrated in sliding contact at 800ºC in vacuum. Tribological performance of several types of ceramic materials was examined with a transfer film formed in different ways in pin/plate friction tests. The transfer film was formed from a Ni-based composite containing BN and graphite as a lubricant.

2. Tester, Specimens, and Test Conditions

Figure 1 shows a schematic view of a 2-pin/plate-type vacuum friction tester used in this study. Two pin specimens are attached to independent pin-arm systems, and loaded against a rotating plate specimen. The pin-arm system is vacuum-sealed using a bellows and is supported by gimbals placed outside the vacuum chamber. The load was applied by hanging a dead weight at air-side-end of the pin-arm system. Friction force was measured using a load cell placed outside the vacuum chamber. The test section was housed in a quartz tube, and the specimens were heated using an infrared heater surround the quartz tube.

The shape and the dimensions of the specimens are showed in Fig.2. The plate specimen had a rectangular shape with a size of 28 mm, and a thickness of 6 mm. The pin specimen had a cylinder shape with a diameter of 8 mm, a length of 35 mm, and the end face was rounded with a radius of 50 mm. The pin/plate specimen materials are listed in Table 1. Two types of Si_3N_4, one type of SiC, and one type of Si-CC (CC composite impregnated with Si) were used as No.1 pin specimen and the plate specimen. In this study, the same material combination for No.1 pin and the plate specimen was examined. A Ni-based composite containing BN and graphite as a lubricant was used as No.2 pin specimen to form a transfer film. All the materials are commercially available, and the compositions are proprietary except for the Ni-based

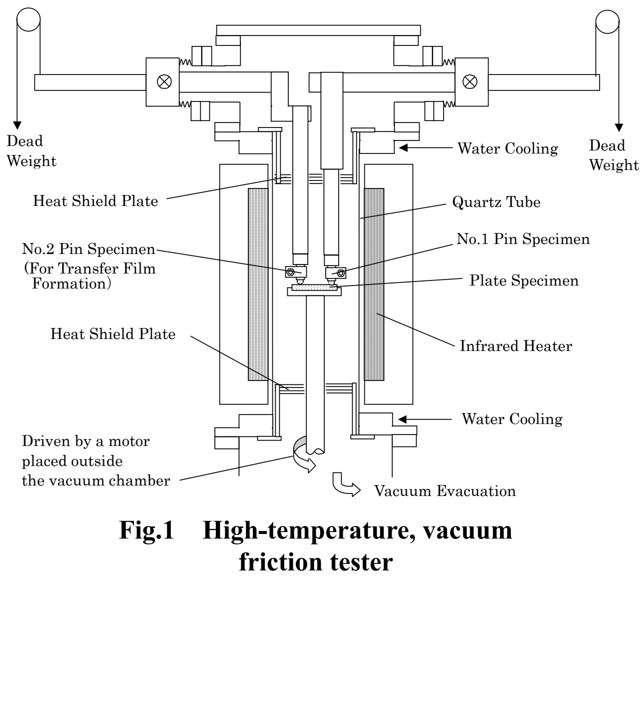
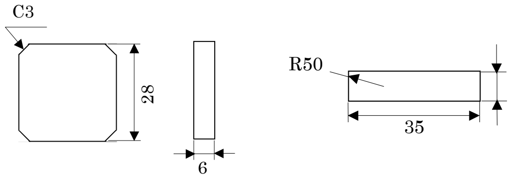


Fig.1 High-temperature, vacuum friction tester



(a) Plate Specimen (b) Pin Specimen

Fig.2 Shape of test specimens

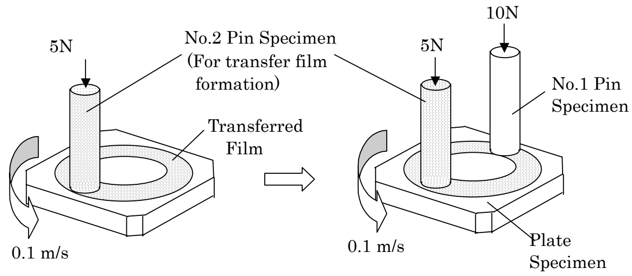


Fig.3 Test configuration to evaluate effectiveness of transfer film lubrication

Table 1 Specimen materials

No.1 Pin / Plate Specimen (Ceramics)

Material	Code	Material	Code
Si_3N_4	AS800	SiC	ES-4
	SN90	Si-CC	SC-01

No.2 Pin (Self-lubricating composite)

Material	Code
Ni-based composite containing BN and graphite (*)	3M1

*Composition: 70% (15%CrB+85%Ni) + 30% (8%BN + 86%Gr) + 6% <Mica + Water glass>)

composite (composition is shown in Table 1).

The friction test configuration is shown schematically in Fig.3. A transfer film was formed in three ways: (1) A transfer film was formed on a plate specimen at 800ºC in vacuum (in the order of 10^{-5} Pa) by rubbing No.2 pin, then No.1 pin was rubbed against the plate specimen on the same track, while No.2 pin was continued to rub throughout friction test (Fig.3). (2) A transfer film was formed in the same way as (1), but No.2 pin was not rubbed during rubbing of No.1 pin /plate. (3) A transfer film was formed at ambient temperature in air (humidity of 50%RH) using another friction tester, then the specimens were mounted in high-temperature friction tester and No.1 pin/plate friction test was carried out at 800ºC in vacuum. In all cases, a transfer film was formed at a load of 5 N, a sliding speed of 0.1 m/s (rotational speed of the plate specimen was 95 rpm) and the rubbing duration of 24 hours. The rubbing conditions for No.1 pin/plate were a load of 10 N, a sliding speed of 0.1 m/s and the rubbing duration of 210 minutes (20,000 rotations). For comparison, tests without a transfer film were also conducted.

3. Test Results

Figure 4 shows change in friction coefficient for 4 material pairs when changed the way of transfer film formation. For comparison, friction of un-lubricated pairs is also shown.

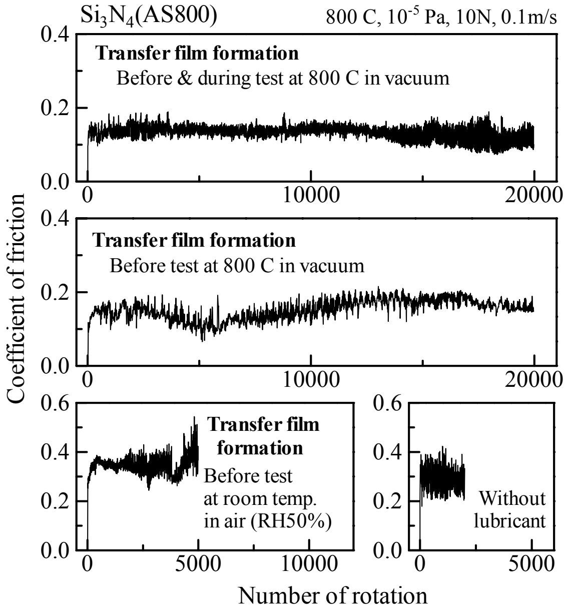
For a Si_3N_4 (AS800) pair, Fig.4 (a), friction coefficient without lubricant was around 0.3, and it was lowered to around 0.15 when a transfer film was formed on a plate specimen at 800C in vacuum. Friction coefficient kept a low value until 20,000 rotations even when the transfer film was not replenished during the test, suggesting that the endurance of the transfer film was good. It was confirmed that the transferred film acted as a good lubricant and give a lower friction. However, friction was higher than that without lubricant when the transfer film was formed in air (RH50%) at room temperature. The temperature and/or the existence of air during transfer film formation seem to affect the nature of the transfer film.

Effectiveness of transfer film lubrication was also confirmed for another Si_3N_4 (SN90) pair, as shown in Fig.4 (b). Friction behavior was very similar to Fig.4 (a) when the transfer film was formed at high temperature in vacuum. For this pair, the transfer film formed in air at room temperature showed certain effectiveness in lowering friction value/fluctuation in the initial stage of testing. Then friction increased at about 2,000 rotations. It seems that the effective transfer film wore out at this time.

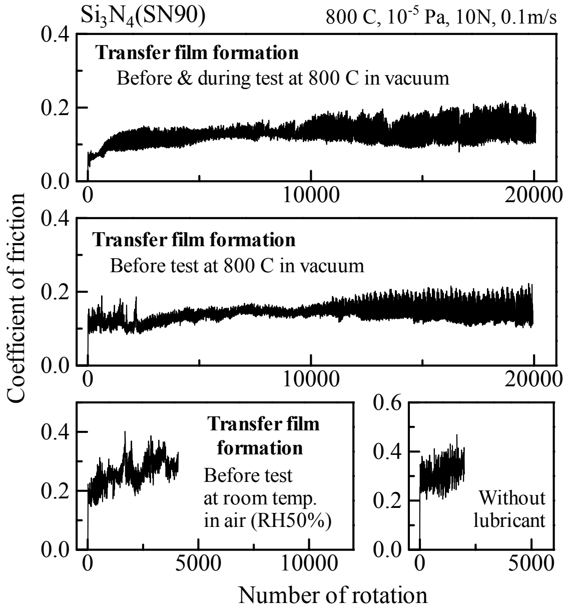
Fig.4 (c) shows friction behavior for SiC (ES-4) pair. Friction coefficient without lubricant was 0.4-0.6 and then decreased to 0.3-0.5, which was much higher than the Si_3N_4 pairs. The transfer film formed in vacuum at high temperature decreased friction to around 0.1. Some scatters in friction were observed when the transfer film was not replenished during the test, indicating that a part of the transfer film was worn but the worn particles re-attached to the friction interface. The transfer film formed in air at room temperature showed limited effectiveness as with the cases of Si_3N_4 pairs. Some transfer film seems to remain on the friction interface until about 9,000 rotations, due to a little lower friction. Then friction behavior became very similar to the test without lubrication.

For a Si-CC (SC01) pair, friction without lubrication was around 0.4, and it decreased to 0.1-.0.15 when the transfer film was continuously supplied to the friction interface. Friction value/fluctuation became a little high when the supply of the transfer film was stopped during the test. To keep low friction, continuous supply of transferred material from a self-lubricating composite seems to be necessary for this pair. Effectiveness of transfer film lubrication was again limited when the film was formed in air.

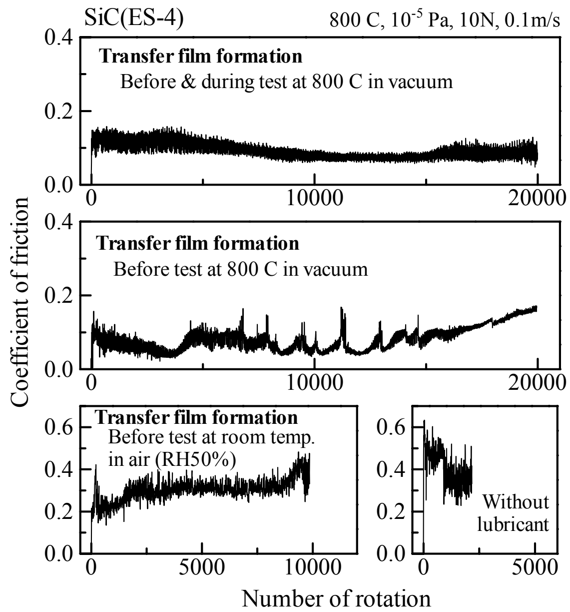
Figure 5 shows surface profiles of pin and plate specimens after the tests. Semi-eclipse lines shown in



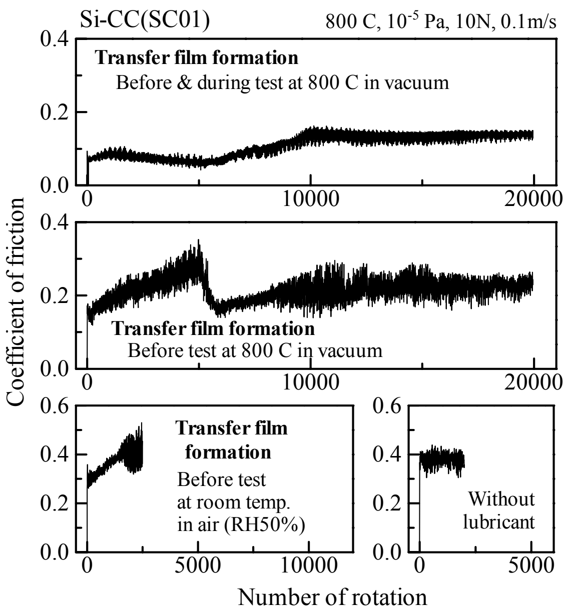
(a) Si_3N_4 (AS800) pair



(b) Si_3N_4 (SN90) pair



(c) SiC (ES-4) pair



(d) Si-CC (SC01) pair

Fig.4 Change in friction coefficient for 4 material pairs when changed the way of transfer film formation

the pin specimen profiles were the estimated original un-worn pin surfaces. After the tests without lubricant, all the specimens had serious wear except for the SiC plate specimen. This clearly demonstrated necessity of lubrication for the tested material pairs, even when the friction value was acceptable for certain applications. By utilizing transfer film lubrication, wear of the specimens was dramatically reduced in most cases.

For Si_3N_4 pairs, there was almost no wear on both pin and plate specimens. A little amount of transferred material was identified on the friction surface in some cases, but a thick transfer film was not observed from the surface profiles. This suggests that the existence of a very thin transferred film was enough to prevent wear. It is worthy to note that the transfer film formed in air at room temperature can also prevent wear of the friction pairs, although friction was not so low.

Thick transfer films were observed on the plate specimens for the SiC and Si-CC pairs when the transfer film was replenished during the tests. However, the transfer film almost disappeared and a little wear was observed after the tests when No.2 pin was not rubbed during the tests. It seems that continuous supply of lubricant is necessary to obtain good tribological performance for these friction pairs.

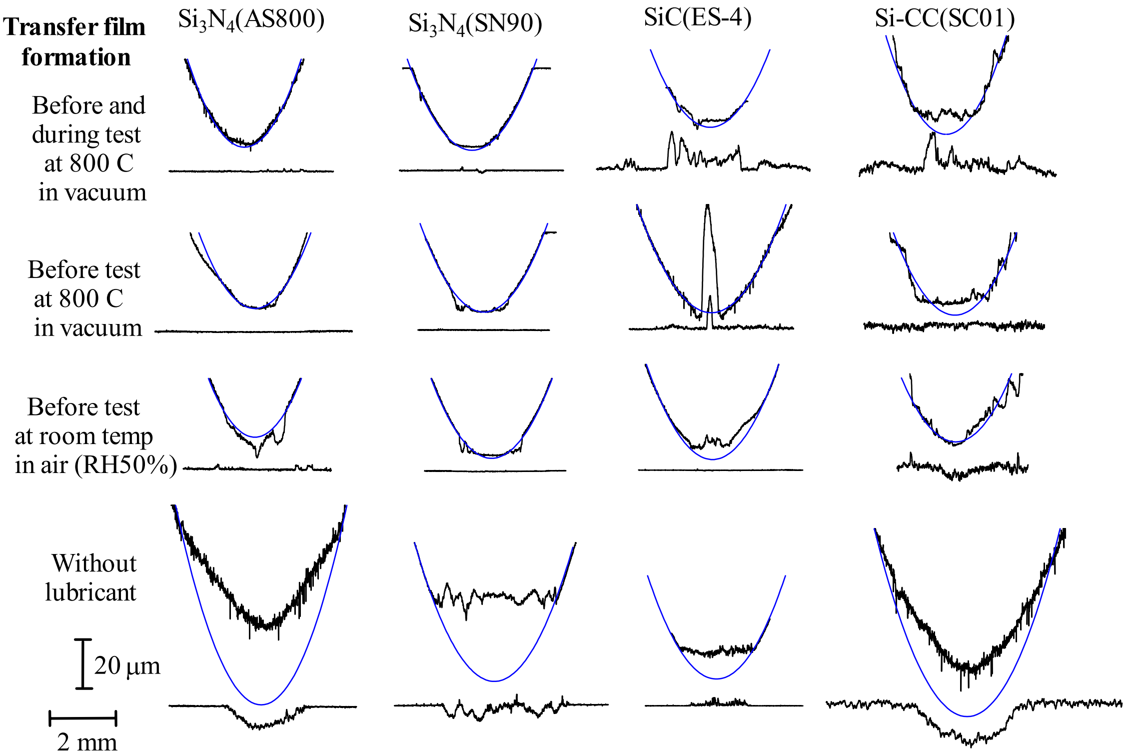


Fig.5 Surface profiles of pin and plate specimens after the tests

Semi-eclipse lines shown in the pin specimen profiles were the estimated original un-worn pin surfaces

4. Summary

Tribological performance of several types of ceramic materials was evaluated at 800ºC in vacuum using a pin/plate type friction tester. When no lubricant was applied, friction and wear was high for all the tested ceramics, suggesting that lubrication is essential for reliable operation at high temperature conditions. By forming a transfer film from a self-lubricating composite, dramatic improvement in wear resistance and decrease in friction was observed. The transfer film prevented surface damage, and almost no wear was observed in some cases. Even when the transfer film was not replenished during rubbing at high temperature, almost the same performance was obtained up to 20,000 rotations. The durability of the transfer film was confirmed to be good.

When a transfer film was formed at ambient temperature in air, it was effective to prevent surface damage until about 2,000 rotations, comparable to the operating times required for moving mechanical components of flaps of re-usable space vehicles. This implies that a transfer film formed in a clean room environment prior to a flight can be used as a lubricant for flaps of re-usable space vehicles. Transfer film lubrication is one of promising candidates of lubrication mechanisms for re-usable space vehicles, although further studies will be needed, such as performance verification in low vacuum conditions where actual mechanical components of re-usable space vehicles will be operated.

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