研 究 速 報
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Friction of Ceramics at Elevated Temperatures up to 1000°C
高温におけるセラミックスの摩擦

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1. INTRODUCTION

Greater attention is being attracted in utilizing ceramics as components in gas turbines and heat engines in realizing increased thermal efficiency and improved performance. It is the high strength at elevated temperatures, good insulating properties and excellent corrosion resistance that expectedly make ceramics possible to satisfy the demands.

Before put ceramics into tribological use in practical engines, amounts of information must be gathered about the friction and wear behavior at high temperatures. It is estimated that ceramic components will be subjected to temperatures up to 1000°C in the systems mentioned above[1]. There have been a number of studies of the friction and wear of ceramics at moderate temperatures (up to about 800 °C)[2)–5)], and experiments at higher temperatures have been started recently[6]. However, much more detailed information on the tribological behavior and understanding of the friction and wear mechanisms of ceramics are required. In this paper, a test system for sliding friction and wear at elevated temperatures up to 1000°C is described, and an initial set of tests on sintered silicon carbide, sialon and alumina is described.

2. TEST SYSTEM

When converting a conventional wear test machine to be able to be used at high temperatures, a cooling system should be carefully designed between the heater and the components subject to the high temperature during the test. Water cooling is adopted in the present design between a heater and bearings and between the heater and strain gages, which is found more effective than oil cooling.

At high temperatures, it is impractical to use oil-based lubricants in friction systems, and therefore the unlubricated friction and wear behavior of ceramics is planned to be studied. Of course, solid lubricants improving the tribological properties of ceramics at high temperatures can also be examined with the present test system.

In spite of the apparently high correosion resistance of ceramics, many have reported that atmosphere has considerable effects on their wear behavior even at room temperature[7),8)]. Hence it seems important to control the atmosphere surrounding the wear specimens in order to obtain meaningful results. Then it is undertaken that, by enclosing the specimens in a vacuum enclosure and filling it with gas of known composition, friction and wear tests are carried out in various atmospheres in the test system. Since ceramics have been found to be very sensitive to the humidity of surrounding atmosphere[9], care is taken to control the humidity of the gases.

The general structure of the test system is shown in Fig. 1. Most components of the system were manufactured from stainless steel. In Fig. 1(b), the evacuating and gas-feeding systems are given schematically.

2.1 Sliding system

The specimen configuration is the widely used pin-on-disc type. The dimensions of the specimens are shown in Fig. 2. One end of the pin specimen taking part in sliding contact was spherically ground to a radius of 3.5mm (Fig. 2(a)). The pin-on-disc assembly in the test system with the oven enclosure

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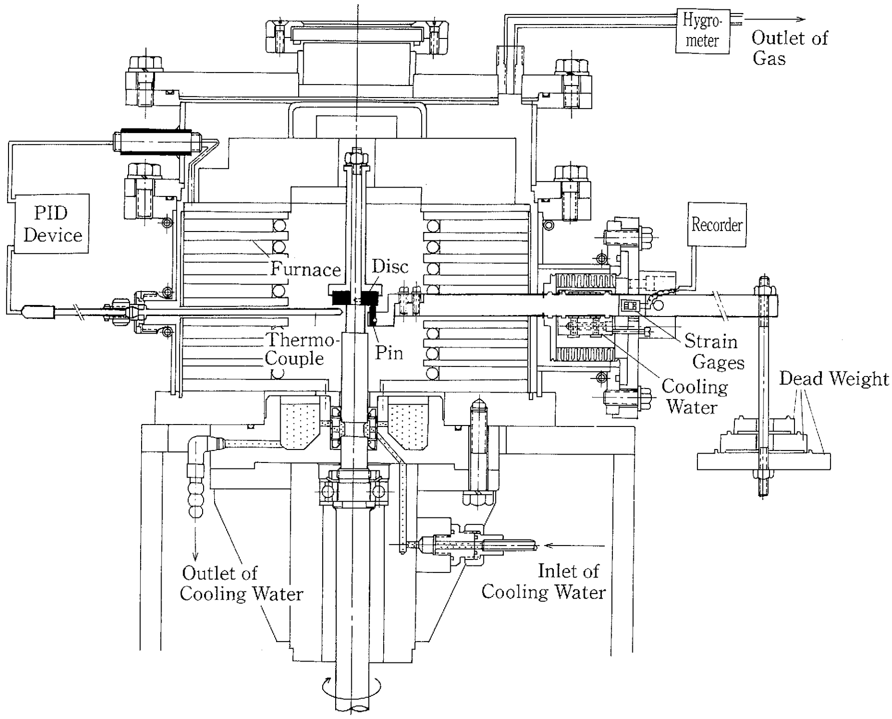
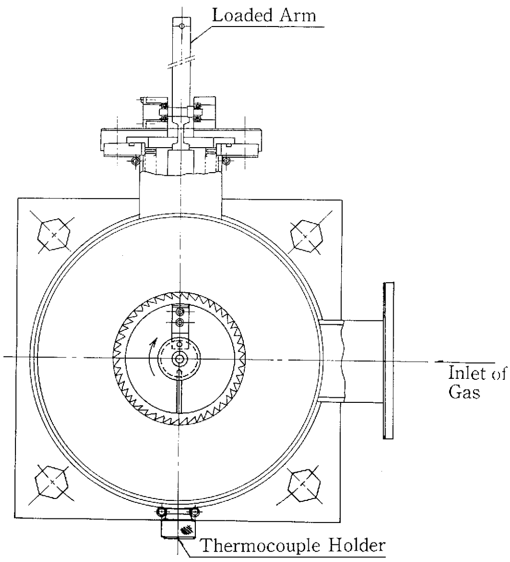
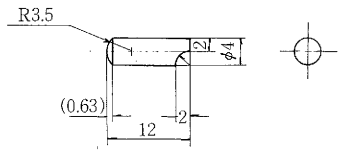


(a)　General arrangement

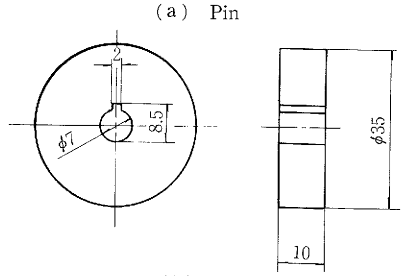


(b)　Vertical view of the vacuum enclosure

Fig. 1　Structure of test system



(a)　Pin



(b)　Disc

Fig. 2　Specimens

removed is shown in Fig. 3. The lower specimen (pin) was fixed in a stainless steel holder which was mounted on a loaded arm, to which a dead weight was applied on the other end outside the vacuum enclosure. The upper specimen (disc) was secured to a rotary shaft with an upper holder, which was driven by a 0.2kW AC variable speed motor. The speed of the motor could be varied continuously from 0 to 1000 rpm. The motor control incorporated a relay which cut off power to the motor when the frictional torque exceeded a pre-set value (normally equivalent to a friction force of 150 N).

2.2 Temperature and environment control

The specimens were heated by a furnace which was mounted in the vacuum enclosure. It is a wire-wound furnace for temperatures up to 1200 °C, surrounded by alumina heat insulating material. The disc specimen was located at the center of the furnace and the specimens were heated through radiation from the heater. The temperature of surrounding atmosphere was measured by an armored thermocouple led through a seal, the tip of which was located opposite to the pin specimen, as can been seen in Fig. 3. The thermocouple output was monitored by a digital thermometer, through which the power supplied to the furnace was controlled by a PID (proportional-integral-derivative) device.

Several holes were bored through the furnace wall for leading the thermocouple and the pin specimen loading arm to the center. For a test in a controlled atmosphere, another hole was opened for the inlet of outer gas. The gases were supplied continuously to the vacuum enclosure. An outlet of the exhaust gas was located on the upper cover of the vacuum enclosure, from which a gas tube was led to a digital hygrometer container, and then to open air.

2.3 Measurements

The friction was measured with two symmetrically stuck strain gages on the arm to cancel the effect of thermal expansion though it was water cooled. The friction and the atmosphere temperature were simultaneously recorded by a two-pen recorder as a function of time, or sliding distance.

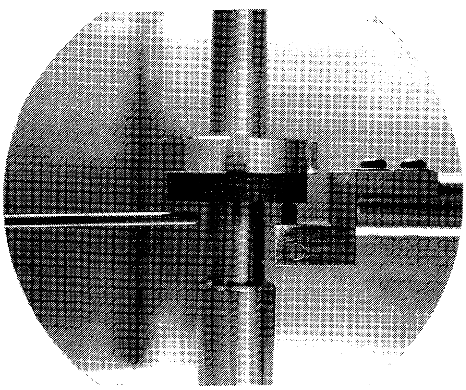


Fig. 3　Specimen assembly

3. RESULTS

Tests were conducted for sintered silicon carbide (SiC), sintered sialon (sialon) and sintered alumina (Al_2O_3). Specimens were prepared to the dimensions given in Fig. 2 and the sliding surfaces were ground to a roughness of 0.1∼0.4 μm Ra. An initial set of tests in dry air is reported in the following. A normal load of 20N was applied and the rotating speed was held constant at 294 rpm which was equivalent to a sliding speed of $0.2ms^{-1}$.

Figure 4(a) shows the variaton of friction coefficient of alumina with temperature. While continuing a run, the temperature was raised from room temperature to 1000°C, during which it was kept constant for about 5 minutes at 20, 200, 400, 600, 800 and 1000°C; then the power supply for the furnace was cut off to let the temperature naturally decrease. It was found that the friction coefficient of alumina was as high as 0.84 at room temperature. With temperature rise it steadily decreased to a lower value of 0.33 at 1000°C, and this behavior was reversed with decreasing temperature.

Tests were performed for SiC and sialon following the same procedure, and the results are shown in Fig. 4(b) and 4(c). It can be seen that the friction coefficient of SiC almost remains constant at a value of 0.72, and did not show significant variation in the temperature range of 20 to 1000°C. On the contrary, the fiction coefficient for sialon showed frequent increases or decreases, particularly in the range between 600 and 1000°C, and was generally higher at higher temperatures. The vibration of the sliding system during test was marked for sialon in comparison with other materials. In spite of such behavior, its friction coefficients at a certain temperature were almost the same in the heating and cooling processes. This was common for all materials, suggesting that the sliding surfaces had their characteristic states which depended on the temperature.

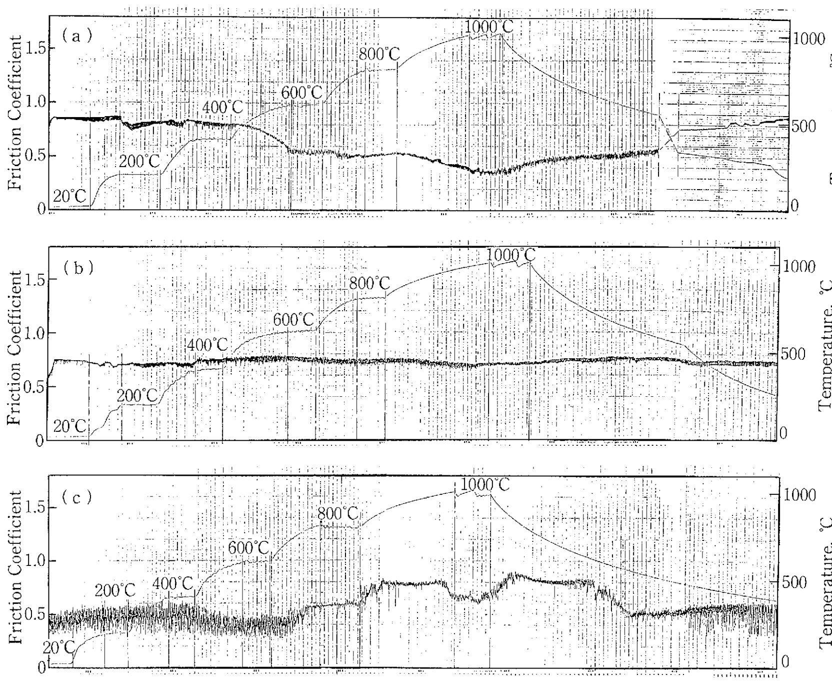


Fig. 4 Variation of friction coefficient with increasing and decreasing temperature
(a) Al_2O_3, (b) SiC, (c) Sialon

4. SUMMARY

A high temperature friction and wear test system has been designed and built for sliding friction and wear tests for ceramics up to 1000°C. The specimen configuration is pin-on-disc, and tests can be performed in open air or in controlled atmospheres under loads in the range of 6 to 135 N, and at speeds up to $0.68 ms^{-1}$.

Preliminary results are given of friction tests carried out at temperatures up to 1000°C on sintered alumina, silicon carbide and sialon.

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