P21

Analysis of seizure resistance of thermally conductive diamond sintered materials focusing on the contact point temperature of sliding parts

Kakeru Ono *, Yutaka Mabuchi *, Satoshi Fujino **, Hiroshi Yamanaka **

Ayumi Nakada***, Kazuhiro Omori***

* Utsunomiya University, ** Tomei Diamond Corporation, *** Industrial Technology Center of Tochigi Prefecture

1. Introduction

As part of efforts to global warming prevention and decarbonization, the downsizing of engines and electrification in automotive powertrains is accelerating. As a result, the load on the bearing material is increasing, and copper alloys and aluminum alloys, which are currently used for slide bearings of engines, are approaching their limits from the viewpoint of seizure resistance. In order to prevent seizure, it is important to keep the contact temperature below the melting temperature of the bearing material, and thus, high thermal conductivity materials which can compress temperature rise are expected to be used in bearing. As one candidate, hydrogen-free DLC film (tetrahedral amorphous carbon, ta-C) is attracting attention, but there are problems in delamination resistance and abrasion resistance under high surface pressure. Therefore, we focused on polycrystalline diamonds (PCDs). PCD is a sintered material made by diamond particles with a metallic binder. It has higher hardness and thermal conductivity than ta-C coating and no delamination and wear [1]. In our previous study [2], the seizure resistance of steel, ta-C film and PCD was investigated, and it was revealed that PCD had higher seizure resistance than ta-C film. However, the effect of PCD's high thermal conductivity in reducing contact temperature could not be confirmed because of a severe test condition that caused seizure. In this study, the influence of thermal conductivity on contact temperature is investigated under mild lubrication condition that do not cause adhesion, and the potential of PCD as a bearing material is discussed.

2. Samples and experimental methods

A schematic diagram of the testing machine in Fig.1. The sliding test was performed using the Amsler tester on the blocj-on-ring method under the fishhook condition in which the upper jig of the block was cooled by circulating water. Sheath thermocouples were inserted into holes located 1 mm and 3 mm from the block surface to measure temperatures at two points during the test. The contact temperature of the sliding part and the heat flux through the block were extrapolated and compared with the contact temperature rise calculated from the prediction formula [3] and analyzed. The prediction equation uses the physical properties of the material (thermal conductivity, density, heat capacity, and Young's modulus), test conditions, contact area, and friction coefficient as parameters. The friction coefficient was used as 0.1 for convenience, because the test machine is not capable of measuring the friction coefficient during the test. The samples were PCD (Tomei Diamond 10BDD, 10TMS) (thermal conductivity 10BDD: 462 W/mK, 10TMS: 727 W/mK) block (5 × 7 × 8 mm), SCM420 and aluminum with ta-C coating and S35C for the ring (φ40 × 10 mm). The test was conducted under the conditions: oil type PAO4 (kinematic viscosity 4 cst at 100°C), oil temperature 100°C, cooling water temperature 50°C, and load 20 kgf. The load was applied at a rotational speed of 50 rpm and accelerated by 50 rpm every 10 minutes until the maximum rotational speed was 200 rpm.

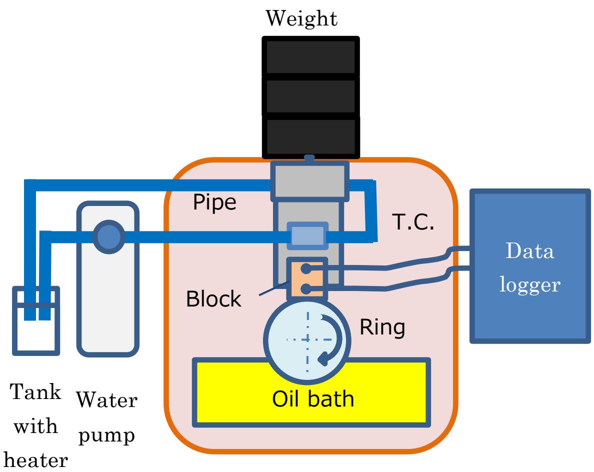

Fig.1 Schematic diagram of test equipment.

3. Results and Discussion

Fig.2 shows the transition of the contact temperature during the test. The contact temperatures during the test were 10TMS, 10BDD, Al+ta-C film, and SCM420+ta-C film in descending order. This matches the order of thermal conductivity, indicating that the use of a high thermal conductivity material improves heat removal. Figure 3 shows the prediction formulas used in this study. From formula (1), the thermal diffusivity k is calculated by the thermal conductivity K, density ρ, and specific heat capacity C. From formula (2), the Peclet number L is calculated from k From formula (3). The heat distribution coefficient for the heat generated in the sliding area flowing to the block side α can be calculated from the thermal conductivity of the block K_1 and the thermal conductivity of the ring K_2. From (4), the contact temperature rise ΔTm is calculated from the amount of heat value by sliding Q and K_1, K_2, L from (2), α L from (3) α. If the thermal conductivity of the block K_1 is high, the denominator of equation (4) becomes large, and the rise in the contact temperature ΔTm becomes small.

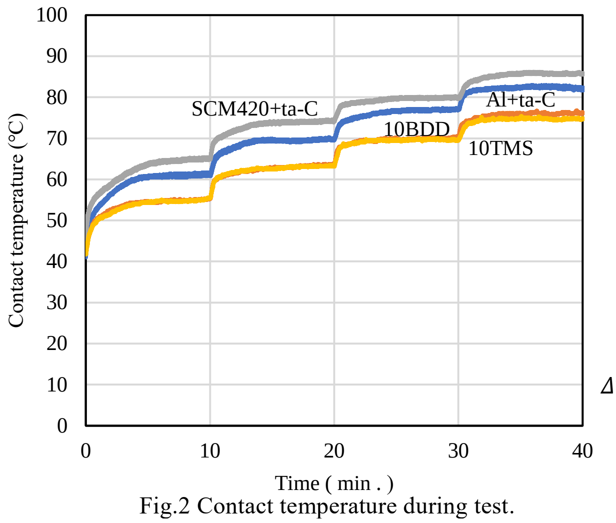

Fig.2 Contact temperature during test.

$$k = \frac{K}{\rho \cdot C} \quad (1)$$

$$L = u \cdot \frac{a}{2k} \quad (2)$$

$$\alpha = \frac{K_1}{K_1 + 0.94 K_2/\sqrt{L}} \quad (3)$$

$$\Delta Tm = \frac{0.254\, Q}{\left(K_1\sqrt{L} + 0.94 K_2\right)\alpha} \quad (4)$$

k : Thermal diffusivity
K : Thermal conductivity
ρ : density
C : Specific thermal capacity
L : Peclet number
u : sliding speed
a : contact radius
ΔTm : Contact temperature rise
α : heat distribution coefficient
K_1 : Thermal conductivity of block
K_2 : Thermal conductivity of ring
Q : Heat value

Fig.3 Prediction formula.

Fig. 4 shows the relationship between the calculated contact temperature rise ΔTm and the thermal conductivity. Even though the prediction formula considers physical properties other than thermal conductivity as influencing factors, the higher the thermal conductivity, the smaller the ΔTm value. The actual measured value of the contact temperature at 200 rpm T, the predicted value of the contact temperature rise ΔTm calculated from the formula, and the gap when the SCM420+ta-C coating is used as the standard for relative comparison are shown in Table 1. The reduction in contact temperature T with SCM420+ta-C was 3.8℃ for the Al+ta-C coating and 9.5℃ for 10BDD. The contact temperature reduction effect of PCD was large. In addition, the difference expanded to 10.7℃ for 10TMS, but the effect tended to be slightly attenuated with respect to thermal conductivity. On the other hand, the gap of ΔTm with SCM420+ta-C coating showed good agreement with the measured value. These results suggest that high thermal conductivity is the main reason for the decrease in contact temperature of the PCD.

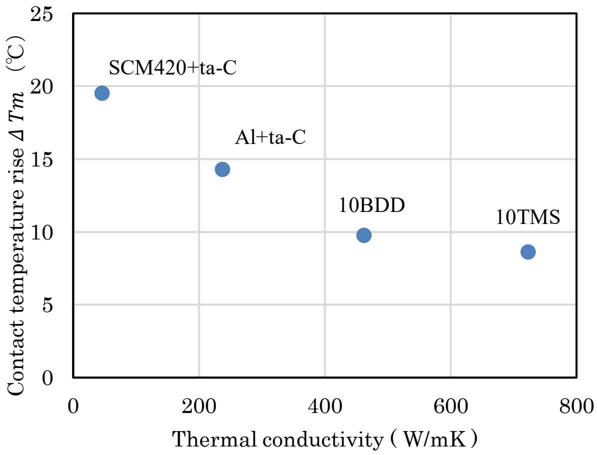

Fig.4 Contact point temperature rise calculated from the prediction formula.

Table1 Contact temperature and calculated Contact temperature rise at 200rpm and gap from SCM420+ta-C.

	Contact temperature T	Gap from SCM420	Calculated Contact temperature Rise ΔTm	Gap From SCM420
SCM420+ta-C	85.6	0	19.5	0
Al+ta-C	81.8	- 3.8	14.3	- 5.2
10BDD	76.2	- 9.5	9.8	- 9.8
10TMS	74.9	- 10.7	8.6	- 10.9

4. Conclusion

The following findings were obtained by evaluating the contact temperature through sliding tests using PCD and comparing it with the prediction formula.

(1) In tests using PAO4 lubrication, the contact temperature of the PCD/S35C combination was significantly lower than that of the SCM440+ta-C film/S35C and Al+ta-C film/S35C combinations, and the contact temperature of the 10TMS combination was lower (727.5 W/ mK) than that of the 10BDD combination (427 W/ mK).

(2) The difference in contact temperature during the test with the SCM420 + ta-C film showed good agreement with the contact temperature rise difference calculated from the prediction formula.

References

1) Ogura Jewelry Precision Machinery Co., Ltd. website: http://www.ogura-indus.co.jp/technology/pcd.php.
2) Ono et al., Tribology Conference 2024 Spring, Tokyo, 220–221.
3) JF Archard, Wear, Volume2, Issue6, October 1959, Pages 438-455.