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Development of direct forming of metal type friction material by thermal spraying

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Abstract

The properties of sprayed coatings were compared with those of sintered metal friction material. Moreover, a production trial test was carried out. The feasibility of applying the thermal-sprayed friction material to actual equipment was assessed. The results are as follows.

(1) The properties, such as hardness, adhesive strength, wear properties, and aggression towards the partner material, of the thermal-sprayed coating were similar to those of the sintered material.

(2) In the production trial test, the coefficient of static friction of sprayed coating ③is equal to that of the sintered material, and the coefficient of dynamic friction of sprayed coating ③is slightly lower than that of the sintered metal friction material.

(3) It is recognized that the friction material formed by thermal spraying can be applied to actual equipment.

Keywords: Thermal spraying, Sintered metal friction material, Adhesive strength, Coefficient of friction, Aggression towards partner material.

1. Introduction

Brakes and clutches are mounted on almost all vehicles, such as automobiles, motorbikes, trains, and bicycles, which are indispensable in modern society. Resin-based friction materials are mainly used for the brakes of motorbikes to improve the braking force. In contrast, sintered metal friction materials are mainly used for the brakes of agricultural and construction machines that require a highly stable and large braking force under high-temperature and high-load conditions. The sintered metal friction materials are manufactured by powder metallurgy. In powder metallurgy, metal powders are compressed and fixed in a die, and then sintered at a high temperature to produce a high-precision product.[1)]

The sintered metal friction materials consist mainly of metal powders such as copper and tin, a graphite lubricant to reduce wear and noise at high temperatures, and oxide such as silica (SiO_2) as a friction modifier. The modifier is used to improve the coefficient of friction and to cut and remove the substance attached to the partner material.

The current manufacturing method of sintered metal friction materials by powder metallurgy requires a number of processes and is time-consuming. To improve the productivity and efficiency, we aimed at developing a method of directly spraying a coating that corresponds to a sintered metal material onto the substrate, rather than attaching a sintered metal friction material to the substrate. There have been very few published reports on the direct spraying of a coating that corresponds to a sintered metal material onto the substrate.[2)] If friction materials are formed on the substrate by spraying, the number of manufacturing processes and the manufacturing time can be markedly reduced. In addition, the simplified manufacturing process of friction materials would be environmentally friendly and lead to energy saving.

Sintered metal friction materials have been used for brakes and clutches of automobiles. In the actual operating environment, continuous load caused by friction is repeatedly applied; therefore, a high adhesive strength between the substrate and the sintered metal material and high wear resistance on the surface of the material are demanded. In addition, these products must be operable for a long time without damaging the partner material. In this study, the required properties of the coating directly sprayed onto the substrate (hereafter, sprayed coating) as a friction material were examined. The evaluation items include the Vickers hardness of the sprayed coating, the adhesion strength between the sprayed coating and the substrate, and the friction properties (the wear resistance and the coefficient of friction of the sprayed coating). In addition, the aggression of the sprayed coating towards the partner material was also evaluated. These values were compared with those of the conventionally used sintered metal friction material. Finally, the sprayed coatings were applied to actual equipment to evaluate the feasibility of using these coatings as a friction material in actual equipment.

2. Experimental method

2.1 Materials

Sintered metal materials consist of copper and tin powders (main components), graphite (lubricant), and an inorganic substance such as SiO_2 (friction modifier). Therefore, the components of the sprayed coatings were made similar to those of sintered metal materials. Three types of sprayed coating [sprayed coatings (1)–(3)] were prepared. Sprayed coating (1) consists of 90%Cu–10%Sn. Sprayed coating (2) consists of 90%Cu–Sn–5%C–5%SiO_2, which is sprayed coating (1) with graphite and SiO_2 added. Sprayed coating (3) is 80%Cu–Sn–10%C–10%SiO_2, which is sprayed coating (2) with increased contents of graphite and SiO_2. The substrate was SUS304 and the thickness of the sprayed coating, formed by atmospheric-pressure plasma spraying, was set to 1 mm. Table 1 summarizes the conditions of atmospheric-pressure plasma spraying.

Table1 Plasma spraying conditions

Powder size (μm)	15〜105
Plasma gas(l/min)	Ar 20
	He 60
Plasma current (A)	450
Voltage (V)	52
Spray distance (mm)	100

The following two specimens were prepared. One specimen was obtained by attaching the conventionally sintered metal material onto the SUS304 substrate by the conventional method (hereafter, specimen with sintered metal material). The other is a copper bulk (C1100) specimen that was used for comparison because the main component of the sintered metal material is copper. Table 2 summarizes the chemical compositions of sprayed coatings (1)–(3), the sintered metal material, and the Cu plate.

Table2 Chemical compositions of sprayed coatings, sintered specimen and Cu plate

	Chemical compositions[wt.%]				Coating thickness [mm]
	Cu	Sn	C	SiO_2	
Sprayed coating1	90	10	0	0	1.0
Sprayed coating2	80	10	5	5	1.0
Sprayed coating3	70	10	10	10	1.0
Sintered specimen	70	10	10	10	1.0 (Sintered thickness)
Cu plate	100	0	0	0	—

2.2 Evaluation items

2.2.1 Observation of microstructure and measurement of Vickers hardness

The cross-sectional microstructures of sprayed coatings (1)–(3) and the sintered metal material were observed using a microscope (VHK-600, Keyence Corporation). Their hardness was measured using a Vickers hardness testing machine (MH-102, Mitsutoyo Corporation) at a load of 100 g.

2.2.2 Adhesive strength

In accordance with the JIS H 8402 "Test methods of tensile adhesive strength for thermal-sprayed coatings",[3] the tensile adhesive strengths of sprayed coatings (1)–(3) and the sintered metal material were measured. Figure 1 shows the experimental setup of the tensile test.[4] For this test, the surface of one cylindrical substrate was sprayed and attached to the nonsprayed surface of another cylindrical substrate using an epoxy adhesive. Jigs were attached to these substrates to carry out the tensile test using a hydraulic universal testing machine. The crosshead speed was set at 0.01 mm/min. Figure 1 also shows the shape of a specimen used with a sprayed coating or a sintered metal material used in the tensile test. The specimens were prepared by spraying a 1-mm thick coating or attaching a 1-mm-thick sintered metal material onto a cylindrical substrate of 25 mm diameter.

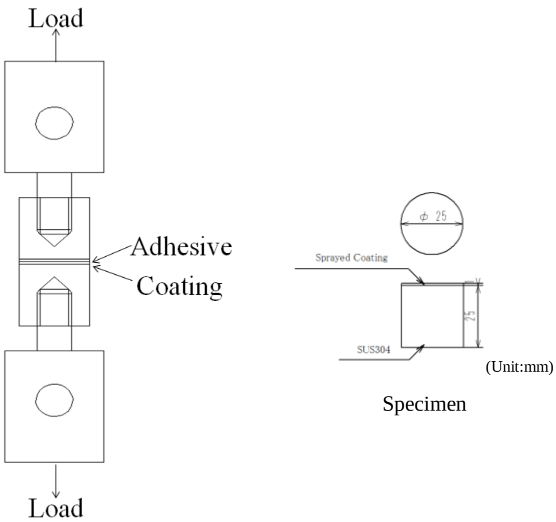


Fig.1 Configuration of tensile test method

2.3 Evaluation of friction property

2.3.1 Block-on-ring test

For the evaluation of the friction properties, the block-on-ring test was carried out to measure the wear resistance and the coefficient of friction. Figure 2 shows a schematic of the block-on-ring test machine.[5)]

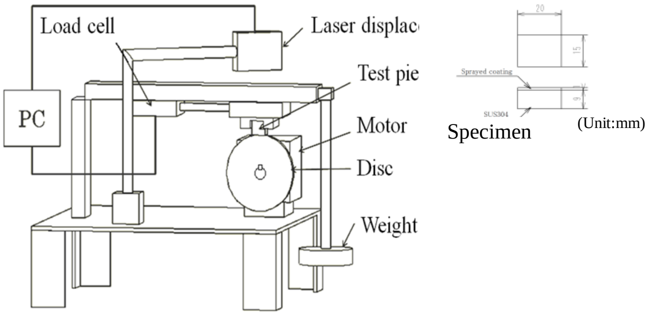


Fig.2 Schematic of block-on-ring test machine

This test machine was assembled on the basis of the "Standard method for wear test (revised)" published by The Japan Society of Mechanical Engineers.[6)]
The disc [Ø100 × 10(t) mm] used as the partner material attached to a motor. Emery cloth was attached to the top surface of the disc and the disc was rotated. The rotating disc was pressed against a specimen. The rotation speed of the motor was controlled using a transmission gear connected to a driver. The load applied to the specimen was changed by adding weight. The partner material was attached to the axis of the motor using screws, and the power was transmitted from the motor to the partner material via a key. The substrate of the partner material was SUS304 [Ø100 × 10(t) mm]. Emery cloth (#400) was attached to the top surface of the partner material. The specimen was fixed to the holder using screws. Figure 2 also shows the shape of a specimen with a sprayed coating or a sintered metal material used in the block-on-ring test. The specimens were fabricated by spraying a 1-mm-thick coating or attaching a 1-mm-thick sintered metal material onto a substrate [20 × 15 × 9(t) mm]. The test conditions of the block-on-ring test were as follows: pressing load, 36 N; rotation speed of partner material, 60 rpm; and duration of test, 30 min.
The wear resistance was evaluated by comparing the wear depth, which was measured at the top surface of the specimen using a laser displacement sensor (HL-C105B-MK, SUNX Limited) and an attached driver (HL-C1C, SUNX Limited). A total of 18,000 data values were collected at 10 Hz for 30 min. The average of every 10 data values was calculated and used as the wear depth for 1 s. The wear depth measured by the laser displacement sensor was used to determine the change in wear depth over time.
The coefficient of friction was calculated as
$\mu = N_2/N_1$,
where N_1 is the load before the test and is equal to the load in the experiment, and N_2 is the load after the test. N_1 and N_2 were measured using a load cell and a load meter. Similarly to the data measured using the laser displacement sensor, the average of every 10 data values was calculated and used as N_2 for 1 s.

2.3.2 Pin-on-disc test

For the evaluation of the aggression towards the partner material (SK4:HV200), the pin-on-disc test was carried out. Figure 3 shows a schematic of the pin-on-disk test machine.[7)]

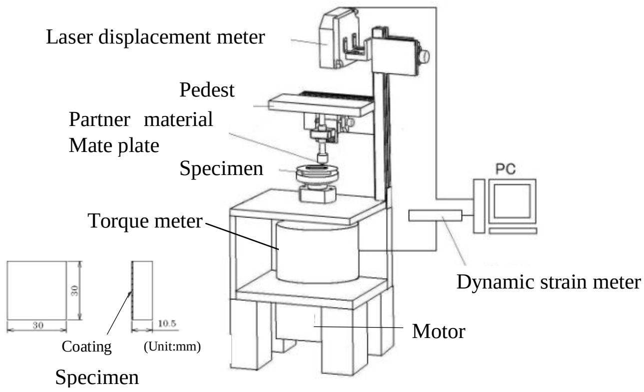


Fig.3 Schematic of pin-on-desk test machine

This test machine was assembled on the basis of the "Standard method for wear test (revised)" published by The Japan Society of Mechanical Engineers.[8)] In the pin-on-disc test, a pin cylindrical specimen with a flat end was made to be in perpendicular contact with the upper surface of a disc specimen under a constant load and the disc specimen was rotated around the central axis for a predetermined period. The states of wear of the disc specimen and the pin specimen (partner material) were examined to evaluate the aggression towards the partner material. The test conditions of the pin-on-disc test were as follows: load to the pin specimen, 21 N; rotation speed, 100 rpm; and duration of test, 4 h. The surface of the disc specimen was polished with emery paper (#2000) to adjust the surface roughness. Figure 3 also shows the shape of a specimen with a sprayed coating or a sintered metal material used in the pin-on-disc test. The dimensions of the pin specimen were Ø4 × 10 mm
The wear depth was evaluated by determining the difference in the length of the pin specimen measured using a micrometer before and after the test. The wear depth of the disc specimen was determined by averaging three measurements obtained at different locations on the disc using a stylus-type surface roughness tester (SURFCOM130A, Tokyo Seimitsu Co., Ltd.)

2.4 Production trial test

Figure 4 shows a schematic of the test machine used in the production trial test. Two disc specimens with sprayed coatings were rotated using a motor. A friction test was carried out while the partner material

(SK4 plate with teeth at the exterior side) was pushed against each side of the disc specimen using a piston in oil.

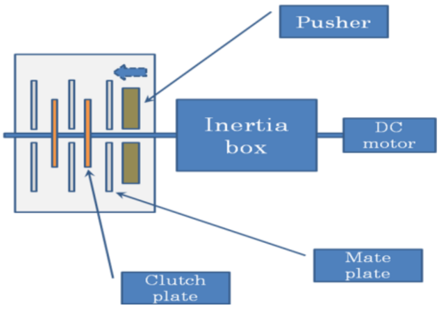


Fig.4 Schematic of production trial examination

This test was carried out using the specimen with sprayed coating (3), which has a chemical composition similar to that of a sintered metal material, and the specimen with the sintered metal material.

The disc specimen was obtained by spraying a 1-mm-thick coating onto both surfaces of a substrate (SK4) with a diameter of 193.5 mm. Teeth were provided at the inner side of the specimen. In addition, another disc specimen was prepared by attaching a 1-mm-thick sintered metal material on both surfaces of a disk substrate (SK4) with a diameter of 193.5 mm.

3. Results and discussion

3.1 Cross-sectional observation of microstructures

In sprayed coating (1), pores are observed; the percentage of pores is approximately 2.4% as calculated by image processing. In sprayed coatings (2) and (3), a small number of black areas that are considered to be carbon are observed. In the sintered metal material, many grey areas are observed.

3.2 Vickers hardness

Vickers hardness was measured at five points on sprayed coatings (1)–(3), the Cu plate, and the sintered metal material, and the average of the five measurements was used as the hardness. Figure 5 shows the results. The Vickers hardness of the sintered metal material is HV107; those of sprayed coatings (1)–(3) are HV106, HV141, and HV209, respectively; and that of the Cu plate is HV77.

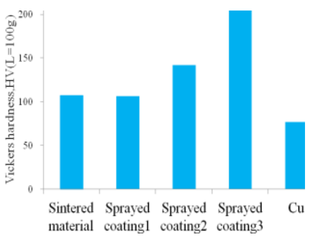


Fig.5 Vickers hardness of sintered material, sprayed coatings①, ②, ③and Cu plate

3.3 Adhesive strength

Three tensile tests were carried out three times using sprayed coatings (1)–(3) and the sintered metal material, and the average of the three measurements was used as the adhesive strength. Table 4 summarizes the results. The tensile strengths of sprayed coatings (1)–(3) are 9.6, 6.8, and 7.1 MPa, respectively, and that of the sintered metal material is 3.5 MPa. The fracture position after the tensile test was at the interface between the sprayed coating and the substrate for sprayed coatings (1)–(3). In contrast, delamination was observed inside the sintered metal material. This difference is considered to be caused by the difference in the fabrication method of sprayed coatings (1)–(3) and the sintered metal mater

Table 4 Results of tensile tests about coating①,②,③and sintered material

	Tensile strength(MPa)	Fractured location
Coating①	9.6	Interface of coating and substrate
Coating②	6.8	Interface of coating and substrate
Coating③	7.1	Interface of coating and substrate
Sintered material	3.5	Sintered material

3.4 Results of block-on-ring test

3.4.1 Wear depth

Block-on-ring tests were carried out three times using sprayed coatings (1)–(3), the Cu plate, and the sintered metal material. The wear depth was measured using a laser displacement meter. Table 5 summarizes the average of measurements.

Table5 Results of block-on-ring test about coating①,②,③and sintered material

	Maximum wear depth (mm)
Coating①	0.55
Coating②	0.32
Coating③	0.28
Cu plate	0.46
Sintered material	0.92

Figure 6 shows the change in wear depth with time. The maximum wear depths of sprayed coatings (1)–(3) are 0.55, 0.32, and 0.28 mm, and those of the Cu plate and the sintered metal material are 0.46 and 0.92 mm, respectively.

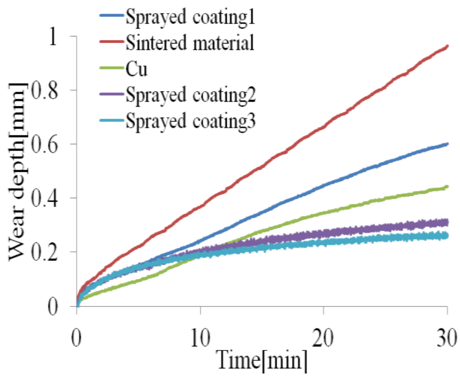


Fig.6 Relationship between wear depth and time for coating①,②,③, Cu plate and sintered material

3.4.2 Coefficient of friction

The coefficients of friction of sprayed coatings (1)–(3), the Cu plate, and the sintered metal material were measured three times. Table6 summarizes the average of the three measurements.

Table6 Results of coefficient of friction measurement

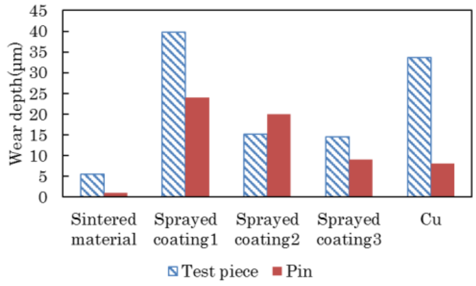
	Coefficient of friction
Sprayed coating①	0.67
Sprayed coating②	0.44
Sprayed coating③	0.36
Cu plate	0.65
Sintered material	0.37

The coefficients of friction of sprayed coatings (1)–(3) are 0.67, 0.44, and 0.36, and those of the Cu plate and the sintered metal material are 0.65 and 0.37, respectively. The coefficient of friction of sprayed coating (3) is similar to that of the sintered metal material. It is considered that the coefficient of friction is largely affected by the presence of graphite and SiO_2.

3.5 Results of pin-on-disc test

The pin-on-disc test was carried out using SK4 (HV200) as the pin specimen and sprayed coatings (1)–(3), the Cu plate, or the sintered metal material as the disc specimen to evaluate the wear depth and the aggression towards the partner material. Figure 7 shows the results. The wear depth of sprayed coating (1) was the greatest (~38 μm) and decreases with increasing amounts of C and SiO_2. The wear depth of the sintered metal material was the smallest (~5 μm).

Regarding the aggression towards a partner material, sprayed coatings (1)–(3) show a similar tendency. The aggression of sprayed coating (3) was the smallest. The aggression of the sintered metal material was very small (~1 μm).



Pin:SK4, Disc:Test piece

Fig.7 Result of pin-on-desk test for coating①,②,③, Cu plate and sintered material

3.6 Results of production trial test

3.6.1 Coefficient of friction

Figure 8 shows the coefficients of static friction (μ_0) of sprayed coating (3) and the sintered metal material. Figure 9 shows the coefficients of dynamic friction (μ_d) of sprayed coating (3) and the sintered metal material. Here, the coefficient of static friction is the maximum momentary coefficient of friction in the vicinity of V = 0 m/s and the coefficient of dynamic friction is the momentary coefficient of friction when the effective circumferential speed (V) is half the initial speed (5.5 m/s). From the results of the production trial test, the coefficient of static friction of sprayed coating (3) is similar to that of the sintered metal material; however, the coefficient of dynamic friction of sprayed coating (3) is slightly smaller than that of the sintered metal material.

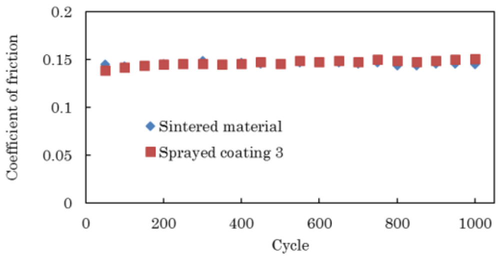


Fig.8 Coefficient of static friction for coating③ and sintered material

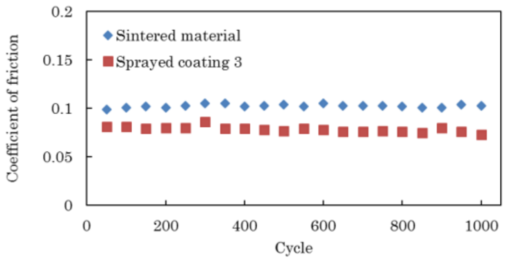


Fig.9 Coefficient of dynamic friction for coating③ and sintered material

3.6.2 Aggression towards partner material

Figure 10 shows the results of aggression obtained in the production trial test. Compared with the results obtained in the pin-on-disk test, the difference in the wear depth between sprayed coating (3) and the sintered metal material is small. This is because the pin-on-disk test is a dry test and the production trial test is a wet test. The tendency of aggression determined in the production trial test is similar to that determined in the pin-on-disk test.

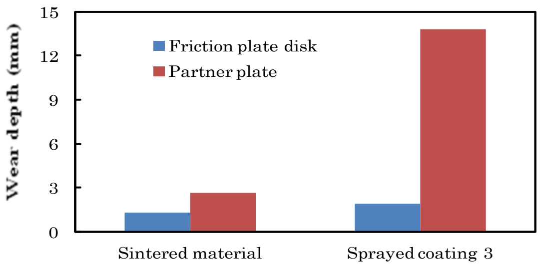


Fig.10 Result of production trial examination

3.7 Over-all evaluation

The Vickers hardness, adhesive strength, wear properties (wear depth and coefficients of friction), and aggression towards a partner material of sprayed coatings (1)–(3) were determined. In addition, a production trial test was carried out. The properties of these sprayed coatings were compared with those of the sintered metal material. The results indicated that the properties of sprayed coating (3) are similar to those of the sintered metal material. The coefficient of friction of sprayed coating (3) obtained in the production trial test is also similar to that of the sintered metal material. The above findings indicate that it is highly possible to apply sprayed coating (3) to actual equipment.

4. Conclusions

The properties of sprayed coatings were compared with those of the sintered metal material. In addition, a production trial test was carried out to evaluate the feasibility of using the sprayed coating as the friction material in actual equipment. We obtained the following conclusions.

(1) The hardness of sprayed coating (1) is similar to that of the sintered metal material, but the hardnesses of sprayed coatings (2) and (3) are higher than that of the sintered metal material.

(2) The adhesive strengths of sprayed coatings (1)–(3) are greater than that of the sintered metal material.

(3) The wear resistance of sprayed coating (3) was found to be the best and that of the sintered metal material the worst from the results of the block-on-ring test. The coefficient of friction of sprayed coating (3) is similar to that of the sintered metal material.

(4) The wear depth and aggression towards the partner material of sprayed coating (3) were found to be similar to those of the sintered metal material from the results of the pin-on-disc test.

(5) The production trial test revealed the coefficient of static friction of sprayed coating (3) to be similar to that of the sintered metal material, while the coefficient of dynamic friction of sprayed coating (3) is slightly smaller than that of the sintered metal material.

(6) The hardness, adhesive strength, friction properties, and aggression towards the partner material of sprayed coating (3) are similar to those of the sintered metal material. Therefore, it is highly possible to apply sprayed coating (3) to actual equipment.

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