Int. J. High Technology Ceramics 4 (1988) 333–340

18

Friction Measurement Between Ceramics and Metals

T. Dickerson

Department of Mechanical Engineering, University of Nottingham,
University Park, Nottingham, NG7 2RD, UK

NOTATION

AF	As fired
CI	Cast iron
G	Ground
N	The normal force per unit thickness of the contact
NI	Nimonic alloy
SN	Reaction-bonded silicon nitride
μ_{max}	The maximum coefficient of friction obtained
μ_p	The first peak value of coefficient of friction in modes A and C (see Fig. 2)
μ_{ss}	The steady state coefficient obtained between 1 and 3 mm of full sliding
$\mu_{0\cdot04}$	The coefficient of friction after 0·04 mm of sliding for mode B (see Fig. 2)

1 INTRODUCTION

Generally, frictional forces cause problems of tensile stresses in contact zones. As engineering ceramics usually fail due to tensile stresses, friction data are essential for design. The aims of this work were to develop a technique for the measurement of the frictional properties of ceramics, to study some of the contact parameters that may affect the friction coefficients

Int. J. High Technology Ceramics 0267-3762/88/$03·50 © 1988 Elsevier Science Publishers Ltd, England. Printed in Great Britain

and to produce friction data over a range of temperatures. This paper deals with the testing apparatus and techniques used. A sample of results is also presented.

2 SCOPE OF TESTS

The work was limited to small relative movements between ceramic and metal components which occur as surfaces start to slide. Typical sliding lengths for the tests were 3 mm.

As metal components were to be used, it was not anticipated that temperatures of greater than 1000°C were necessary.

Investigations included: the effects of normal force, sliding velocity, contact geometry, different material combinations and surface finish. The results shown here are mainly for reaction-bonded silicon nitride discs in the 'as-fired' state in contact with ground cast iron and Nimonic bars; but an example with reaction-bonded silicon nitride and aluminium discs and bars is also quoted. The sliding rate was constant at 1 mm/min.

3 COMPONENT DESIGN AND LOADING

To model a realistic type of contact and keep the test components simple, a rectangular bar was clamped between the edges of two discs. This created two line contacts. The Hertz theory may be used to calculate the contact width (Johnson, 1985) because it is small compared to the component dimensions. Typical contact widths in this work were from 0·1 mm to 0·4 mm. The coefficient of friction was calculated from the clamping force and the total tangential force required to pull the bar between the discs. The discs used were 25 mm in diameter and 4 mm thick, and the bars were 4 mm square in cross-section. The required surface finish can easily be produced on the bars and discs. A number of individual tests could be produced from each set of components (two discs and one bar) by rotating the discs and moving the bar to obtain virgin surfaces.

4 LOADING SYSTEM

A standard Instron universal testing machine gave displacement-controlled, constant-velocity sliding between the bar and discs. The total tangential force and cross-head movement were obtained from the chart recorder. The components were positioned and the forces transmitted by a fixture and collet as shown in Fig. 1. The clamping force was produced by weights acting

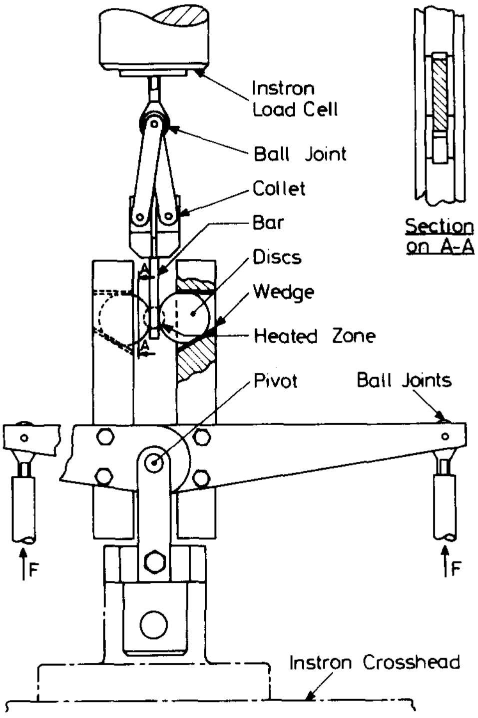

Fig. 1. The main features of the friction test fixture.

through a system of levers. The lever system also kept the discs symmetrically disposed about the centreline of the testing machine. Details of the lever system have been omitted from Fig. 1 for clarity. The discs were located by slotted wedges, which transmitted normal force and prevented rotation. The wedges also compensated for differential thermal expansion and kept the thermal conduction path between disc and fixture small. Air gaps between the sides of the discs and the fixture also kept the conduction path small (see Section A–A in Fig. 1). These measures enabled the fixture to be kept relatively cool. The maximum temperature of the 316 stainless steel fixture was about 500°C with a component temperature of 1000°C. The test bar was attached to the load cell by a stainless steel collet chuck. Two stainless steel set screws were used to clamp the bar between the two halves of the collet (the set screws are omitted in Fig. 1).

5 COMPONENT HEATING AND TEMPERATURE CONTROL

Two 750 W infra-red radiant spot heaters, designed to produce a heated spot 6 mm in diameter, were defocussed to produce heated zones of 10 mm diameter as shown in Fig. 1. Each side of the components was heated by a separate unit. The infra-red heating was rapid and localised, keeping the hot zone close to the contact area, thus enabling conventional materials to be used for the fixture and collet. Typical heating times, for room temperature to 500, 900 and 1000°C, were 30 s, 3 min and 8 min, respectively. With this arrangement, a maximum temperature of 1025°C could be achieved.

The heaters were wired in series to a variable transformer. A single thermocouple was used to monitor the temperature of the components; it was welded to the bar, at the centre of the hot zone. The thermocouple junction was shielded from infra-red radiation by a refractive sheath. The temperature was controlled manually. With care, the temperature could be kept to within ±10°C.

6 TEST PROCEDURE

The as-fired SN surfaces were prepared by removal of the loose α-silicon nitride whiskers on the surface with a clean buffing wheel. The bars were surface-ground in the direction of sliding. Inhibosol was used to degrease the components before testing.

The surface finish of the components, in the direction of sliding, was measured. The values are shown in Table 1.

After locating the components, as in Fig. 1, the normal force N was applied through the fixture, using weights. The normal force was kept constant throughout each test. Heating was carried out and the cross-head travel started when the temperature had stabilised. The cross-head displacement versus the load cell force was plotted by the chart recorder. Some of these records are shown in Figs 2 and 3 with the force axis rescaled to show coefficient of friction.

TABLE 1
Surface Finishes for the Friction Test Components in the Direction of Sliding

Quality	*Material*		
	SN	*CI*	*NI*
Component	Disc	Bar	Bar
Process	AF	G	G
Finish/(μm CLA)	2·5	0·3	0·7
SD (μm CLA)	0·4	0·06	0·34

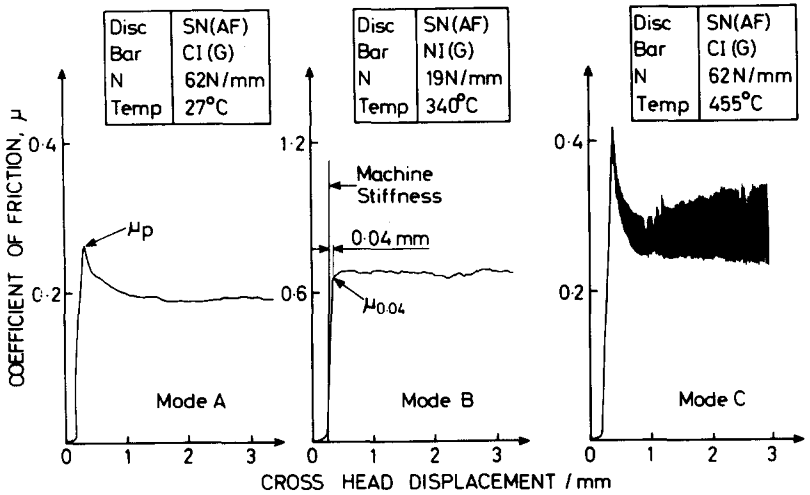

Fig. 2. Typical force displacement records for the three modes of behaviour.

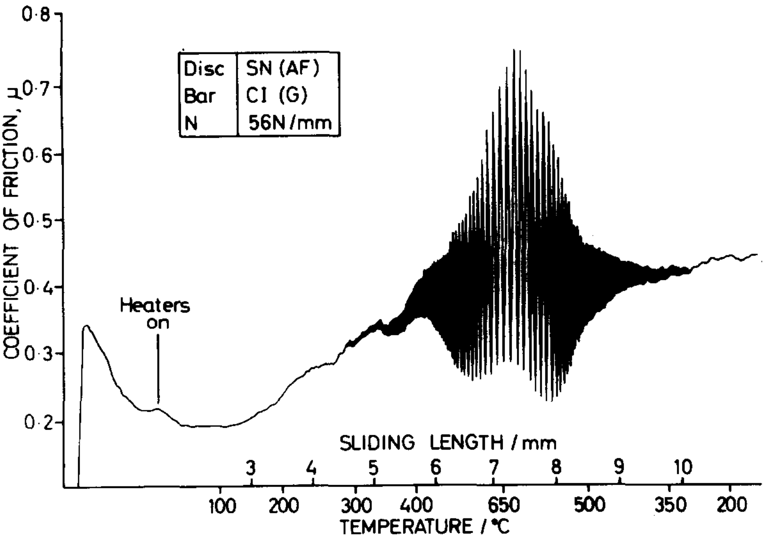

Fig. 3. Temperature-dependence of stick–slip.

The combined fixture and machine stiffness was determined by using components bonded at the contacts. A correction was applied to the displacements as shown in Fig. 2(b).

7 FRICTIONAL AND WEAR BEHAVIOUR

In general, the softer material is transferred to the harder during sliding. When the disc is harder, the bar material becomes impregnated in the disc and eventually the contact can, in extreme cases, be between similar materials. If the bar is harder, the material transferred to the bar is pulled out of the contact zone and a fresh abrasive area enters the contact. For reaction-bonded silicon nitride and aluminium, at room temperature, this fundamental change in the contact caused the μ-displacement curve to change from mode A, with reaction-bonded silicon nitride discs, to mode B, with aluminium discs. The values of $\mu_{0 \cdot 04}$ and μ_p differed little between the two types of contact but μ_{max} and μ_{ss} changed considerably. This shows that the sliding configuration is also important. Fessler & Fricker's (1984) investigations of reaction-bonded silicon nitride sliding on hardened steel were in the second category; their μ-displacement curves were similar in form to mode B (Fig. 2).

Three modes of behaviour were identified from the force-displacement graphs; these are illustrated by typical records in Fig. 2. Modes A and B were not unusual; mode C, however, shows a stick–slip action. The magnitude of

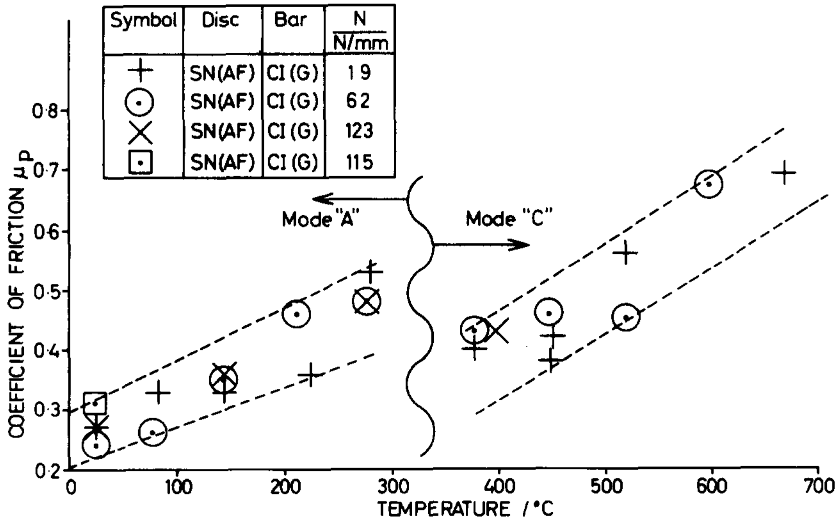

Fig. 4. The effect of normal force magnitude for cast iron bars.

the stick–slip forces was found to be highly temperature-dependent, rising with increasing temperature. Figure 3 illustrates the temperature-dependence of the stick-slip; this recording was produced by increasing and then decreasing the temperature while the bar was sliding between the discs at a constant rate. For the materials tested, stick–slip only occurred with cast iron at temperatures above 300°C.

Figure 4 shows a set of results for as-fired, reaction-bonded silicon nitride on cast iron for a range of temperatures and normal forces. No dependence of μ_p on normal force is indicated. Fessler & Fricker (1985) found that the coefficient of friction was also independent of normal force for cone-in-taper tests. In Fig. 4 general increase with temperature is apparent. However, a discontinuity occurs when changing from mode A to C.

8 CONCLUSIONS

A fixture to adapt an Instron universal testing machine to measure frictional forces has been successfully completed and used.

Infra-red spot heaters were found to be a convenient way of causing localised, rapid heating.

The components used are relatively easy to manufacture with the required test surfaces and allow several tests per component set.

The way in which the contact is modified by material transfer needs to be considered.

Stick–slip may occur with cast iron above 300°C.

For contact of reaction-bonded silicon nitride discs on cast iron bars, the coefficient of friction was generally found to increase with temperature and to be independent of the magnitude of the normal force.

ACKNOWLEDGEMENTS

This work was supported by the Admiralty Research Establishment (Holton Heath) under the terms of a SERC CASE studentship. The author wishes to thank Professor H. Fessler, Dr D. J. Godfrey and Dr J. J. Webster for their friendly advice.

REFERENCES

Fessler, H. & Fricker, D. C. (1984). Friction at broad and narrow contacts between silicon nitride and hardened steel. *Proc. Brit. Ceram. No. 34*, August 1984, 129–43.

Fessler, H. & Fricker, D. C. (1985). Friction in femoral prosthesis and photoelastic model cone taper joints, submitted to Eng., In Medicine.

Johnson, K. L. (1985). *Contact Mechanics*, Cambridge University Press, Cambridge, 1985, pp. 99–104.