FRICTION OF CARBONS
PART 1: FRICTION WEAR AND TRANSITION

Khalid Lafdi and Kia Moh Teo

Carbon Research Laboratory
University of Dayton Research Institute,
300 College Park, Dayton, OH 45469 USA

Introduction

When two carbon materials are rubbed together, friction and wear properties are always very predictable. For given conditions, they might have a very significant change. Friction transitions have been observed in which the value of the coefficient of friction changes drastically. Many published articles show the variation of the coefficient of friction in regard to time, pressure and temperature. Blau subdivided such transitions into eight stages [1,2]. But, the variation of friction coefficient is often subdivided into three regions: run-in, mild wear and transition to severe wear. Many models were developed to predict the variation of the coefficient of friction as a function of time. Some of these models could predict the run-in time of a bearing surface and checking the reproducibility of a surface contact condition [3]. Some models have great success in predicting the average of coefficient of friction. However, the term average friction coefficient is very misleading because of the presence of friction transitions. Asperity models based on mechanical deformation have also been developed but many friction details are neglected such as the effect of debris, material compositions and other surface reactions. Kuhlmann-Wilsdorf's model that relates the coefficient of friction to asperity properties, shear stresses and microstructures is not sufficient to cover the actual sliding conditions [4]. Transition phenomena at the surface have been described as combination of multiple effects such as subsurface fatigue damage, wear-through of surface film, build-up of transfer layers, agglomeration of debris and change of material properties [1-5]. He also mentioned that the magnitude of the friction coefficient during transition is proportional to the formation of wear debris. Studies on the structure of friction film, its formation could be one of the ways to understand friction and wear mechanisms [6,7].

Experimental Procedures

A sintered carbon composite was prepared for the friction test. The tests were performed using a standard test machine (Friction Assessment Screening Test "FAST") . All samples were tested for 90 minutes under various constant frictional forces in which only the rotational velocity was varied. A K-type thermocouple embedded in the middle of the sample at 2.5 mm from the sliding surface recorded the temperature history of the entire test period. In situ video capturing of surface evolutions and visual examinations were also conducted to understand the development of the friction film and its relationship to friction transition.

Table 1 shows the testing conditions performed. Tests 1 to 6 of various rotational speeds were used to generate various total energies absorbed per minute. The frictional force was kept constant and adjusted to a value of 69.7 N. From test 7 to 12, various rotational speeds and a frictional force of 104.6 N were used to study the effect of higher frictional forces.

Table 1 Testing Conditions

Sample #	Velocity (m/sec)	Friction Force (N)	Power Input (W)
1	350	69.74	137.95
2	450	69.74	177.35
3	550	69.74	216.75
4	650	69.74	256.16
5	750	69.74	295.63
6	850	69.74	335.03
7	350	104.61	206.92
8	450	104.61	266.02
9	550	104.61	325.13
10	650	104.61	384.23
11	750	104.61	443.44
12	850	104.61	502.55

Results and Discussions

All curves clearly show the sudden changes in the friction coefficient. Depending on the testing conditions, the coefficient of friction profile as a function of time exhibits either single or multiple friction transitions (increase of coefficient of friction from the base line). Figure 3a shows a typical trend in friction coefficient during friction transition.

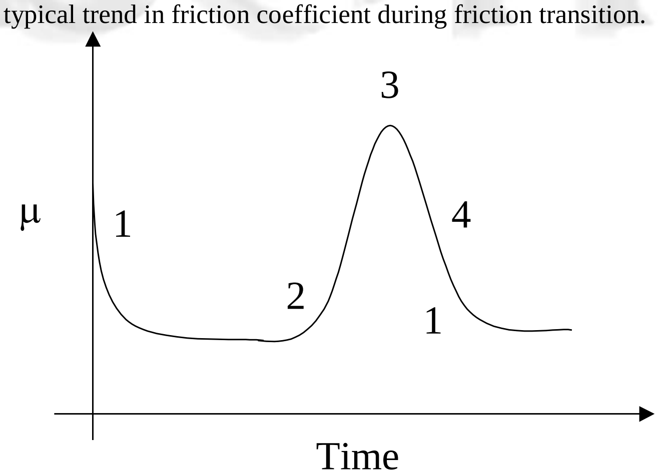

Fig. 1 Model illustrating multiple stages of the coefficient of friction variation as a function of time (regardless the velocity and power input values).

As shown in Figure 2, the coefficient of friction initially has a value of ~ 0.3 and as the test progressed with time the coefficient of friction decreases to a value of 0.16. the coefficient of friction is stabilized for a short period at point of 0.16. Then, the transition occurs and the coefficient of friction increases up to a value of 0.6. When the transition is over, the coefficient of friction begins to decrease. The same pattern may be repeated many times. At the beginning of the test, the bulk temperature (2.5 mm from the surface) increases rapidly from the room temperature to a value of 200 °C within few seconds during run in process (it depends on testing conditions, the rate of temperature increase can exceed 10 °C/sec). Then, the temperature increases gradually at a rate of 0.05 °C/sec. After that, it remains steady at about 290 °C. However, at the first glance of the transition, a fast increase of bulk temperature is recorded with a rate between 0.2 – 0.45 °C/sec. After the transition, the temperature continues to increase very slowly due to the gradual wear of the sample.

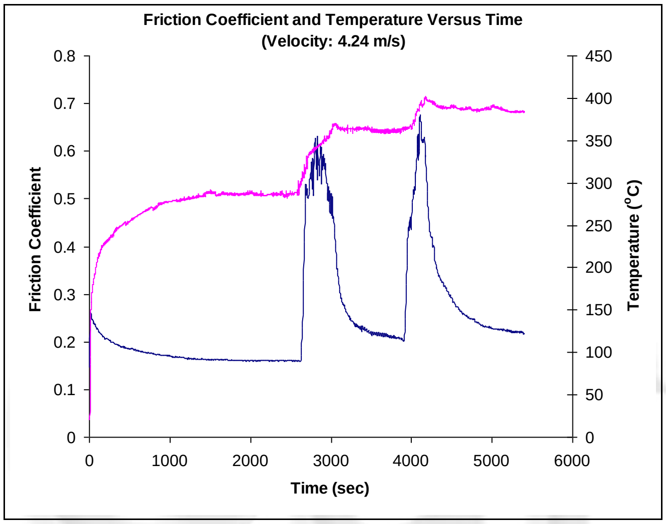

Fig. 2 Variation of coefficient of friction and temperature as function of time for a velocity of 4.24 m/sec and frictional force of 69.7 N.

Characterization of friction surface at different stages

Friction surfaces for all experiments exhibit some specific characteristics in which they can be summarized as follows:

(1) Prior to friction test, sample surface was polished with sand paper up to the grid size of 800. For all experiments, same surface finish is managed. Also, the surface profile is taken before and after each test.

(2) Before friction transition, the sample surface appears very shiny and relatively smooth.

(3) At the first indication of the transition, the coefficient of friction starts to increase and some surface alterations. The friction surface of the sample appears to be made of two distinct bands or wear tracks: one is shiny (i.e. smooth) with some relative waviness and the second is dull with some random surface irregularity (i.e. rough). During the friction transition, dull slits (powdered wear track) appear with localized roughness, cracks and voids.

On the other hand, the smooth part was observed to have polished bands and/or bands with some granular structure. This smooth part was made of a smeared friction film in which agglomeration of tiny particulates has occurred. These particulates with narrow range of sizes and shapes are highly compacted. The structure of the smeared film is made of low order carbon. Indeed, there is a structural change from very straight and anisotropic structure in form of graphitic structure into quasi-less crystalline and amorphous type structure. We believe that the degree of compaction is strongly dependent on the testing conditions (i.e. normal load, time and initial velocity). However, this smeared friction film might often be disrupted and contain cracks.

(4) During the transition, the powdered film expanded to reach the entire rubbing surface. The sheared particulates tend to form very compacted and smeared particulates with a narrow range of sizes and shapes in which the bonding force appears to be very large. At some locations, the interfaces between particulates can be observed without any apparent gap between them even at nanometric scale. However, the dull part of the friction surface is clearly made of disrupted film particulates. For given testing conditions, The dull areas tend to expand and the surface becomes rougher in comparison to the shiny part. The number and the width of these dull tracks are strongly dependent on the testing conditions (normal load, time and velocity) and gas environment (argon, humidity and air). At some locations in the dull area, cracks and holes are very obvious. The cracks are either empty or filled with wear debris. The extension and the magnitude of these bands and their shapes depend on many parameters (oxidation, thermal expansion, thermal stresses and others). However there is always a fair matching at macro-metric scale between friction surfaces of the rotor and stator.

After the transition, the sliding surfaces gained back the same surface characteristics and properties. It consists mainly of very shiny surface with fine particulates.

References

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