Wear 376-377 (2017) 1528–1533

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Physical model of adhesive wear in early stage of sliding

K. Fukuda [a,b,*], T. Morita [c]

[a] Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur 54100, Malaysia
[b] International Institute for Carbon-Neutral Energy Research (I2CNER), Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan
[c] Faculty of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan

ARTICLE INFO

Article history:
Received 3 September 2016
Received in revised form
4 January 2017
Accepted 20 January 2017

Keywords:
Adhesive wear
Wear model
Wear mechanism
Friction force
Dry sliding
Specimen displacement

ABSTRACT

A physical model of adhesive wear mechanism needs to be improved from quantitative aspect as possible to predict phenomena in the real world. The model should also be able to provide necessary information for the design of tribo-mechanics in logical manner. In this research, an attempt on explaining how saw teeth shape in the chart of specimen displacement perpendicular to the sliding surface for tribo-testing of adhesive wear using a quantitative simulation method had been made. Some simple processes i.e. sliding, accumulation of material and transfer of the accumulated material, which appear in the very early stage of sliding, are subjects of simulation in this research. A simple model which consisted of limited number of parameters could achieve success to simulate experimental data to some extent and mimicked the selected simple processes. The research clarified the limitation of the proposed model. Necessary additional parameters should be shape and size of a transfer unit and shear strength at interface of sliding with theoretical background. It is necessary to define those parameters theoretically based on scientific knowledge to comprehend the sliding phenomena.

1. Introduction

Tribology is one of the engineering fields. This means that tribology should be able to provide appropriate techniques to predict tribology phenomena and necessary information for the design of tribological mechanics in the real world based on theory. However, especially for adhesive wear, researchers' attempts to provide a practical and physical model which can illustrate the phenomena satisfactorily have achieved limited success. This is serious problem because the adhesive wear occupies a major part of tribology related troubles in terms of surface damage such as the sudden transition from mild to severe adhesive wear. A seizure problem which is accompanied by suddenly raised friction force and the generation of large adhesive substances in stainless steel made threaded fasteners is typical example of the troubles. For the practical engineering purposes in tribology field, years of empirical data and formulas but not theories based on scientific knowledge have been employed for solving problems and designing devices. Usage of coefficient of friction and wear maps [1–3] which have been obtained experimentally are good examples of the employments of empirical data. It is obvious that theoretical explanation using a physical model based on the scientific understanding on adhesive wear mechanism is necessary for the exponential development in tribology field.

The development of the physical model of an adhesive wear mechanism started with elemental one proposed by Holm in 1946, and then by Archard in 1953 [4]. A model proposed by Sasada and Norose in 1970s [5] named “mutual transfer and growth process of wear particle formation” is one of the most successful models in explaining the various aspects of adhesive wear qualitatively. However, from a quantitative viewpoint, even Sasada's model does not perform satisfactorily to predict the phenomena in the real world. Obviously deep quantitative understanding of adhesive wear is indispensable to improve the physical model.

Some of the efforts made to understand adhesive wear phenomena were headed to atomic to nano-level approaches such as experimental analysis using SPM (scanning probe microscopy) [6,7] and numerical simulations e.g. molecular dynamics simulations on interactions of atoms etc. [8,9]. Although those most advanced approaches have successfully provided various new knowledges which show the possible development in tribo-elements in future, the knowledge provided is limited to the interactions between outmost surfaces of solid material in ideal environment such as complete vacuum or perfectly pure gases. This means that quantitative comprehension on the phenomena with larger scale is necessary to be studied to bridge the previous abstract models and the knowledge provided by atomic-to-nano-level approaches for the establishment of the complete, fully theoretical and practical model of adhesive wear.

* Corresponding author at: Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur 54100, Malaysia.
E-mail address: fukuda.kl@utm.my (K. Fukuda).

http://dx.doi.org/10.1016/j.wear.2017.01.078
0043-1648/

The research group of the current authors has been studying the adhesive wear mechanism experimentally and quantitatively. So far, as the first step, the study has been limited to the very early stage i.e. first several rotations of sliding for the pin-on-disk tests, because the phenomena manifesting during this period of sliding appear in this stage scarcely maintain their simplicity. We decided to start our study in the very early stage since comprehension of phenomena after a number of repeated sliding is extremely difficult because the phenomena are highly complicated. One of previous studies revealed the existence of initial steady period (ISP) in the very early stage of sliding in which no significant microscopic adhesion were detected [10]. We extended our research to the quantitative evaluation of adsorbed water on the metallic surface because the length of ISP varied in different rates of relative humidity of experimental environment. The extended research found that the surface of austenitic stainless steel in air with medium rate of relative humidity is covered with adsorbed water layer with around 50 nm thickness which is equivalent to the average roughness of mirror finished surface [11]. The thickness of adsorbed water layer should have influenced the sliding phenomena such as ISP significantly [12]. In addition, elemental processes of adhesive wear mechanism in early stage of sliding were studied and summarized as shown in Fig. 1 [13] using a devised technique [14–18]. Sliding, accumulation, transfer and overriding are typical elemental processes observed in the early stage of sliding. Including rolling, kicking and back transfer of an adhesive substance, the sequence of the elemental processes in adhesive wear process can be illustrated as a diagram shown in Fig. 2. The elemental processes can be categorized into 2 groups i.e. long events and short / instant events.

In this study, as the first step towards improving the physical model of adhesive wear in terms of quantitative manner, experimental data in the very early stage of sliding is looked into. The selected elemental processes, i.e. sliding, accumulation and transfer are simulated using known material properties and black box functions to know which variable triggers the transition between the processes. The black box functions which employ supposed influencing independent variables are assumed to estimate how those

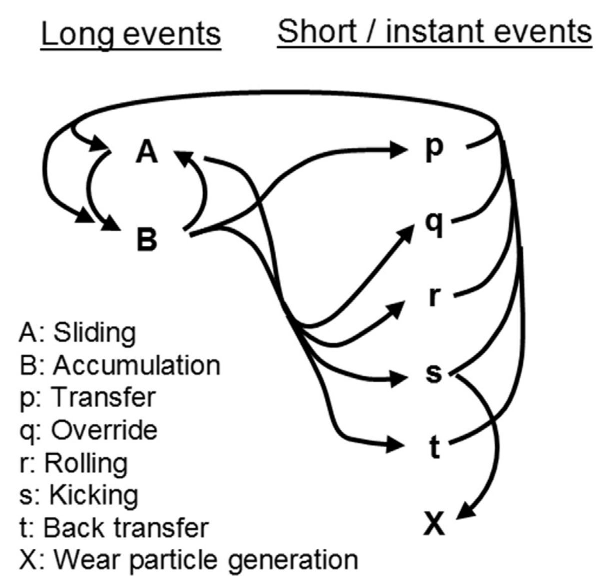

Fig. 2. Possible sequences of elemental processes of adhesive wear mechanism.

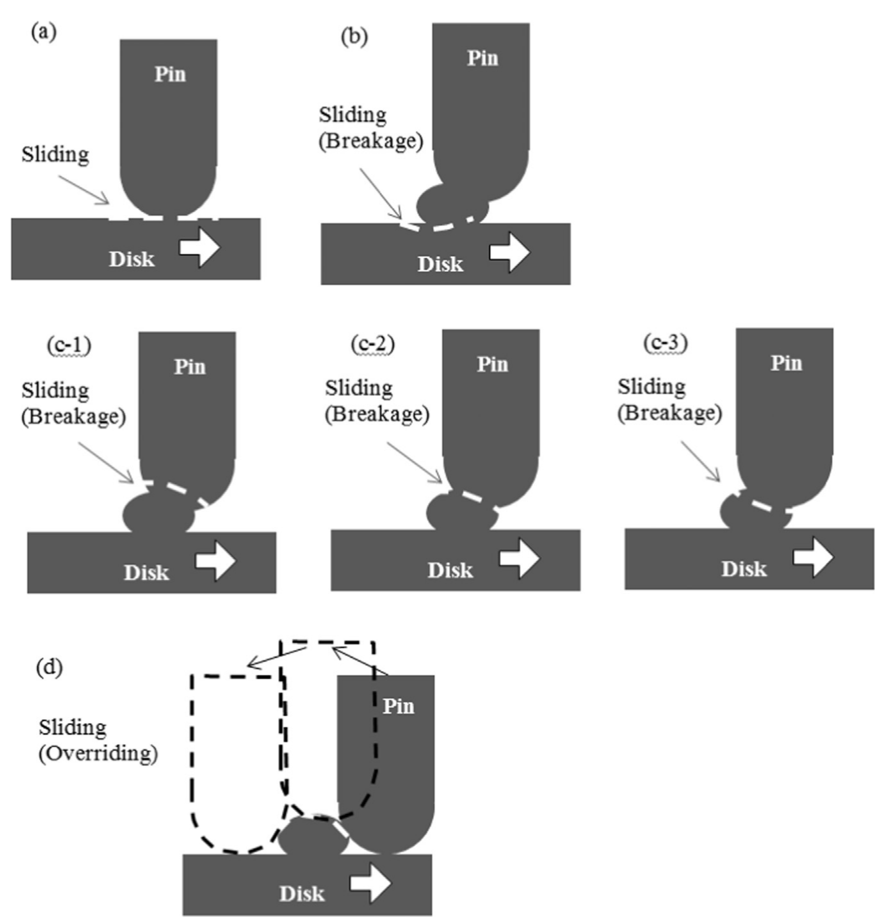

Fig. 1. Proposed elemental processes of adhesive wear mechanism (a) sliding, (b) accumulation, (c-1, 2, 3) transfer and (d) overriding [10].