Tribology International 98 (2016) 292–298

Contents lists available at ScienceDirect

Tribology International

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

Friction and wear characteristics of magnetorheological elastomer under vibration conditions

Chenglong Lian, Kwang-Hee Lee, Chul-Hee Lee *

Department of Mechanical Engineering, Inha University, 253 Yonghyeon-dong, Nam-gu, Incheon 402-751, Republic of Korea

ARTICLE INFO

Article history:
Received 30 November 2015
Received in revised form
24 February 2016
Accepted 24 February 2016
Available online 2 March 2016

Keywords:
Friction coefficient
Wear
Magnetorheological elastomer (MRE)
Vibration

ABSTRACT

In this study, the friction and wear properties of magnetorheological elastomer (MRE) were examined under various vibration conditions. The variation of the friction coefficient and wear of the MRE was investigated experimentally with an applied magnetic field and different frequencies and amplitudes of normal vibration. To accomplish this, a reciprocating friction tester and test samples were designed and fabricated. The results show that the friction coefficient decreased with the magnetic field in all test conditions. The friction coefficient increased when vibration was applied and the frequencies were increased. The friction coefficient decreased as the amplitudes increased. The wear also significantly changes under different vibration frequencies and amplitudes with and without a magnetic field.

1. Introduction

Magnetorheological (MR) materials are a type of "intelligent" material [1,2], and their properties can be changed under the influence of an external stimulus. Magnetorheological elastomer (MRE) is a type of MR material that is widely studied in mechanical applications. The shear and hardness of MRE can be changed by an external magnetic field. The R&D laboratory of the Toyota Center developed a silicone gel containing iron particles for engine mounts [3]. The Ford Research Laboratory developed MREs with natural and synthetic rubber [4]. Chen investigated the MREs based on natural rubber [5]. Hu developed a new MREs based on polyurethane/Si-rubber hybrid [6]. Xu and Liao developed an active-damping-compensated MRE adaptive tuned vibration absorber [7]. Recent studies have shown that the friction coefficient can be altered by an external magnetic field due to the changing hardness of the MRE [8,9], which could lead to a wide range of developments in tribology.

Many types of mechanical or automotive equipment experience vibration. Moreover, the friction and vibration can affect each other. For example, friction can cause vibration through stick-slip. The change of friction force depends on the roughness of the rubbing surfaces, relative motion, type of material, temperature, normal force, stick-slip, relative humidity, lubrication, and vibration. Godfrey studied that the vibration reduces metal to metal contact and causes an apparent reduction in friction [10]. Skare studies the static and dynamic friction processes under the influence of external vibrations [11]. Lehtovaara found the influence of vibration on kinetic friction between plastic and ice [12]. The frequency and amplitude of vibration can also be used to adjust the friction force. Tolstoi studied the friction deduction by perpendicular oscillations [13]. Chowdhury studied the effect of amplitude of vibration on the coefficient of friction for different materials [14–19].

As a smart material, the friction coefficient of MRE can be reduced under a magnetic field, and applications in engineering have widely been studied [8,9]. However, the friction properties of MRE under vibration conditions had not been examined yet. In this study, the effect of normal vibration on the friction of MRE was investigated under different vibration frequencies and amplitudes. MREs were manufactured, and a tester was set up to conduct a friction test for the MRE under vibration. The friction coefficient was measured to evaluate the friction properties under different vibration conditions, and then the wear depth and surface profile of the MRE were observed to evaluate the wear properties.

2. Experimental specimens

Silicone-based MREs have been shown to have the best MR effect and are widely used in various medical, mechanical, and vehicle applications for their non-toxicity and stable properties like aging resistance [1–5,8]. Thus, silicone was used as the matrix for MREs in the present study. Fig. 1 shows the MRE specimen used in the tests. The thickness of the specimen was determined by considering the MR effect and the strength of the magnetic

* Corresponding author.
E-mail address: chulhee@inha.ac.kr (C.-H. Lee).

http://dx.doi.org/10.1016/j.triboint.2016.02.037
0301-679X/

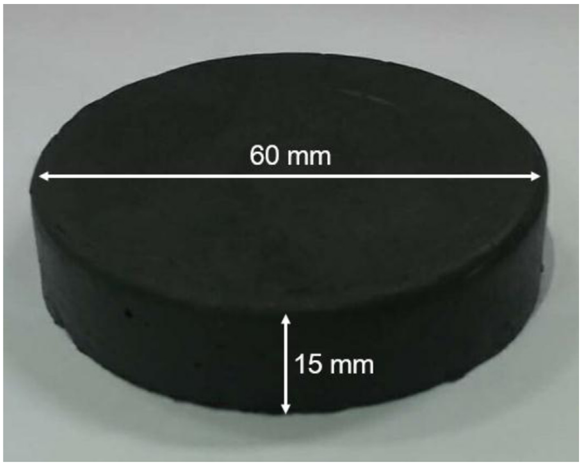

Fig. 1. MRE specimen and its dimension.

field. If the MRE is too thick, the contact surface will be too far from the electromagnet and the strength of the magnetic field may be insufficient. If it is too thin, rapid penetration could occur due to the softness of the elastomer. Referring to the previous literature [8,9], the thickness of the MRE was thus set to 15 mm.

The shape of the MRE was designed as a circular plate with a diameter of 60 mm based on the electromagnet shape to ensure that a uniform magnetic field would be applied. The average size of the interior carbonyl iron (CI) particles was about 10 μm, and their proportion by weight was 79.8 ± 2.0%. This level of CI content was confirmed to produce the best uniformity and MR effect for this size and weight of MRE through many tests [9]. The fabrication process of the MREs is mainly divided into mixing, hardening, and cooling steps. A vacuum air pump was used to eliminate as many air bubbles in the MRE as possible to reduce their impact on the experimental results.

A reciprocating friction tester was used to evaluate the friction properties of MRE under vibrating conditions, since reciprocating friction often appears in actual situations. Fig. 2(a) and (b) shows a schematic diagram and photograph of the friction tester, respectively. The tester includes function generators, an amplifier, shaker, electromagnet, MRE, pin, laser displacement sensor, indicator, slider, personal computer, and two loadcells. To determine the heat of the MRE contact surface during tests, the temperature was measured with a laser temperature sensor (Testo 835).

A ball shape with a diameter of 10 mm was designed at the end of the aluminum pin to prevent excessive tearing on the surface of the MRE due to the softness of the elastomer. The pin directly contacts the surface of MRE, which is located on the electromagnet. The shaker is placed below the electromagnet to generate vibration. The pin connects with the horizontal slider, which is driven by Labview and produces a reciprocating movement. The sliding stroke was set to 20 mm with a reciprocating frequency of 0.5 Hz, which results in a sliding distance of 10 mm per second.

Because the MRE cannot bear high surface heat, the load was set to about 1.5 N and the velocity was set to 10 mm/s. The friction distance was set as 2000 mm, and the strength of the applied magnetic field was 80 mT. The vibration amplitude was measured by a laser displacement sensor. Two loadcells were set up in both the horizontal and vertical directions to measure the horizontal force and vertical force in real time. The friction coefficient was calculated by Coulomb's law. The friction forces are collected by indicators and transferred to a personal computer by Labview.

Before tests, the resonant frequency of the experiment system was measured to check if it would affect the results. Fig. 3 shows the frequency response results, which indicated a resonant frequency of 2100 Hz. In the first stage of the test, the friction

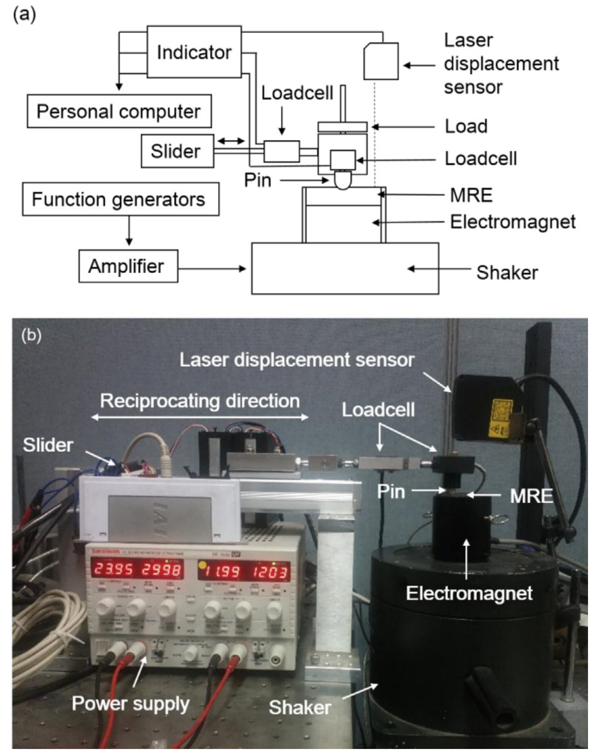

Fig. 2. Experimental setup: (a) schematic diagram, (b) photograph of the friction tester.

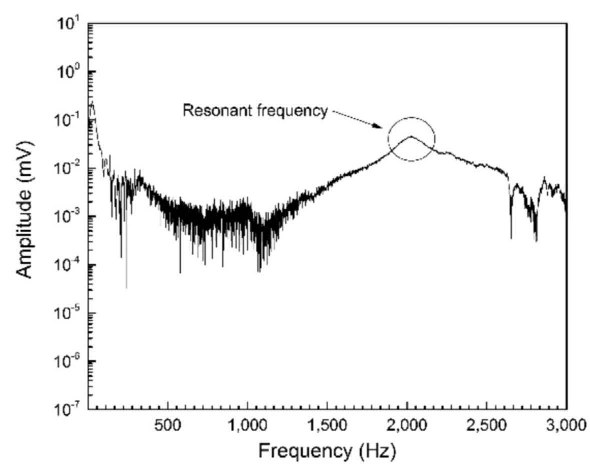

Fig. 3. Frequency response of experiment system.

property of the MRE was measured under no vibration as a baseline. Then, the friction property of the MRE was measured under different vibration frequencies and amplitudes in the second stage. Each test was repeatedly conducted for three times and the results were obtained from the average value of test results.

3. Results and discussion

3.1 Friction property

SEM images of the MRE surface were taken, as shown in Fig. 4. The white CI particles were distributed in the substrate, which is gray. When a magnetic field is applied, the CI particles gather and the hardness increases. Before tests, the hardness of the MRE was measured with a Mitutoyo HH-300 shore durometer. When a magnetic field of 80 mT is applied, the hardness of MRE is