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Dry sliding friction of ethylene vinyl acetate blocks: Effect of the porosity

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ABSTRACT

This study is the first attempt to investigate the dry sliding friction characteristics of ethylene vinyl acetate (EVA) blocks with varying porosity (α) values. The sliding friction tests indicated that the porosity significantly influenced the friction coefficient (i.e., the friction coefficient decreased with α when $\alpha < 50\%$ and increased with α when $\alpha > 50\%$). The EVA blocks with a higher porosity ($\alpha > 80\%$) showed larger friction coefficients than the non-porous EVA block. Contact area observations on a glass plate revealed an elastic collapse at the anterior part of the porous EVA blocks with a higher porosity. A simplified model considering the elastic collapse of porous EVA blocks via elastic buckling of the cell walls explained the effect of the porosity on the friction coefficient in terms of adhesion friction. Thus, the higher α provided larger contact areas as a result of the increase in the elastic collapse area at the anterior part of the apparent contact area, thereby resulting in high friction coefficients. These results may provide an insight into new usages of porous polymers as high friction materials.

1. Introduction

Porous polymers have been widely used in a variety of applications (e.g., insulation, cushion, and absorbents, among others) [1,2] owing to their low heat or sound transfer properties, flexibility, softness, large surface area, and low-density (i.e., lightweight) characteristics. According to their structure, porous polymers can be classified into open and closed cell structured [3]. The former materials are composed of cell edges with interconnected cavities. Thus, open cell polymer foams possess higher permeability and superior absorptive capabilities as compared to closed cell structured polymers [4,5]. Closed cell structured porous polymers are composed of cells with edges and walls. These cells are isolated while the cavities are surrounded by cell walls. Therefore, closed cell polymer foams have lower permeability and therefore better insulation properties [6].

Closed cell structured porous ethylene vinyl acetate (EVA) has been used as a midsole for running shoes [7], owing to its high cushioning and lightweight characteristics. EVA foams are significantly less dense than rubber materials, such as butadiene rubber (BR) and styrene butadiene rubber (SBR), typically used as outer sole materials for running shoes. Porous EVA with high friction characteristics could be used as outer sole materials for running shoes. This approach would result in weight reduction and structural simplification of the shoe soles while providing new usages for porous polymer materials. However, the frictional behavior of porous EVA has not been studied and still remains unclear.

Some studies have been previously conducted on the friction characteristics of porous metals [8,9] and ceramics [10–13]. Under oil lubrication, the surface of the pores in porous metals act as oil pockets, thereby supplying lubricant at the contact interface and reducing friction as a result [8,9]. Under dry conditions, Hamid et al. [11] investigated the dry friction and wear characteristics of in situ cast composites with various porosity (α) values when slid against hardened steel, and they found that friction increased with α. They claimed that the contact area decreased with α, thereby resulting in larger contact pressures. Therefore, both wear and the friction coefficient increased with α. These porous metal and ceramics presented α values lower than 10%, and the effect of α on the friction coefficient of porous materials under a wide range of α has not been investigated.

Herein, we prepared non-porous and porous EVA blocks with various α (46.0%–89.3%), and investigated the effect of α on the friction coefficient of these materials against a smooth stainless steel surface under dry conditions.

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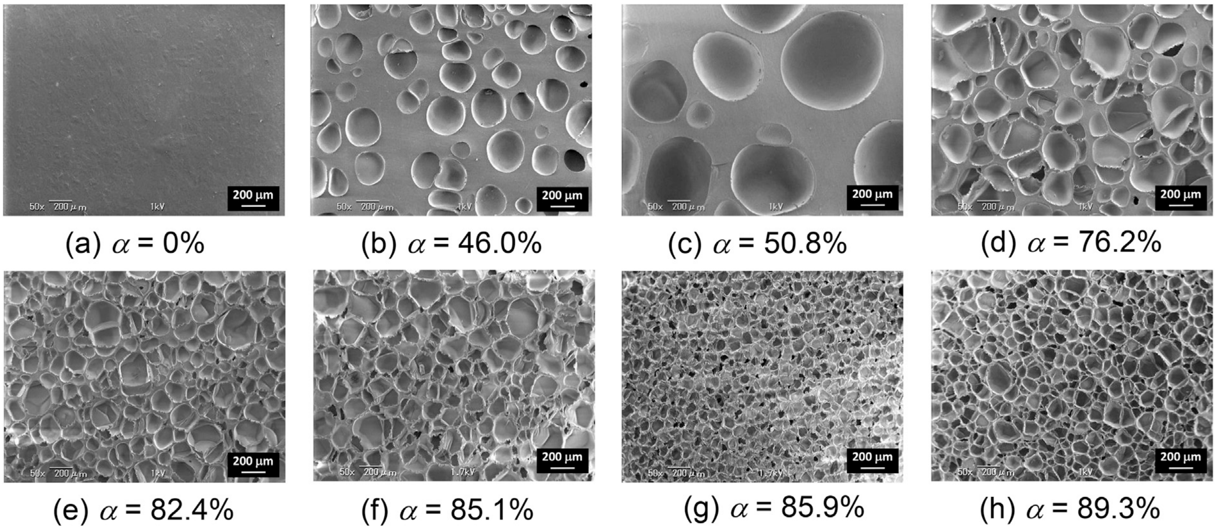

Fig. 1. Scanning electron microscopy (SEM) images of (a) non-porous ethylene vinyl acetate (EVA) and (b)–(h) porous EVA blocks with various porosities.

Table 1
Porosity, mean pore diameter, and mechanical properties of non-porous and porous ethylene vinyl acetate (EVA) blocks.

Porosity α, %	0.0	46.0	50.8	76.2	82.4	85.1	85.9	89.3
Mean pore diameter d, µm	–	303.6	629.5	279.1	140.8	167.8	91.1	117.6
Density ρ, Mg/m^3	0.9	0.5	0.5	0.2	0.2	0.1	0.1	0.1
Breaking strength σ_T, MPa	11.9	4.2	3.6	2.1	1.6	1.3	1.6	1.1
Breaking strain ε_T, %	576.0	393.9	344.1	418.6	379.0	221.5	323.6	304.9
Initial tensile modulus E_T, MPa	44.5	13.7	12.0	4.9	3.2	3.5	3.6	0.6
Initial compressive modulus E_c, MPa	48.0	10.0	15.3	4.2	3.0	3.1	2.5	1.4

2. Material and methods

2.1. Material preparation

Non-porous and porous EVA block specimens with different α were prepared by the following process. The EVA polymer, along with the foaming and crosslinking agents, was compounded and sheet shaped by a calendaring process. The sheet was subsequently pressed at 160 °C under a compressive pressure of 15 MPa for 10 min. The porosity was controlled by the amount of the foaming agent. Non-porous and porous EVA sheets were cut into a blocks (10 mm × 10 mm × 5 mm). Fig. 1 shows scanning electron microscopy (SEM) images of the surface of the non-porous and porous EVA blocks with different α. As shown in Fig. 1, the porous EVA blocks showed a closed cell structure.

α [%] for each porous EVA specimen was calculated using the following equation:

$$\alpha = \left(1 - \frac{\rho^*}{\rho_s}\right) \times 100, \tag{1}$$

where ρ^* [Mg/m^3] and ρ_s [Mg/m^3] are the densities of the porous and non-porous EVA specimens, respectively. The pore cross-section for each porous EVA specimen shown in Fig. 1 was an ellipse, and the lengths of the major and minor axes of the ellipse were measured. The equivalent pore diameter d [µm] (diameter of a circle having an area equal to the pore cross-section area) for the porous EVA specimen was subsequently calculated using the following equation:

$$d = \sqrt{ab}, \tag{2}$$

where a [µm] and b [µm] are the lengths of the major and minor axes of the pore cross-section, respectively. The porosity, the mean pore diameter, and the mechanical properties of prepared specimens are summarized in Table 1. The porous EVA specimens showed α values ranging from 46.0% to 89.3%. The breaking strength and strain, the tensile modulus, and the compressive modulus of the porous EVA specimens were found to decrease with α.

2.2. Sliding friction tests

Fig. 2 illustrates the experimental setup used for the sliding friction tests. The friction tests were conducted on a linear motion type friction tester under dry conditions. An austenitic stainless steel plate (JIS SUS304, 100 mm × 50 mm × 2 mm) with a surface roughness (Ra) of 0.02 µm was affixed onto the linear motion stage. The non-porous or porous EVA block specimens were affixed onto the specimen holder and subsequently contacted with the plate specimen. A normal load was applied with a weight, and the stage was subsequently driven in a linear fashion. Before each sliding test, the steel plate specimen was ultrasonically cleaned in hexane for 10 min and subsequently dried under a low-vacuum atmosphere. The EVA block specimens were wiped with a nonwoven fabric impregnated with ethanol and subsequently dried under a low-vacuum atmosphere. Table 2 summarizes the experimental conditions used in these tests. The normal load was 4.9 N, while various sliding velocities (v) were used (0.001, 0.01, or 0.1 m/s). The sliding distance for a single friction test was 0.03 m (for 0.001 and 0.01 m/s) and 0.07 m for 0.1 m/s. The tests were conducted at a relative humidity of 40± 5% and a laboratory temperature of 20 ± 2 °C. The sliding friction tests were replicated 15 times under the same conditions using 15 samples with identical porosity.

The friction force was measured with a load cell connected to the upper specimen holder, and the sampling frequency of the friction force was 100 Hz. The friction coefficient was calculated by dividing the frictional force by the normal load.

3. Results

Fig. 3 shows the representative friction coefficients for the non-