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# Effect of porosity on friction coefficient of polymer foam blocks under dry condition

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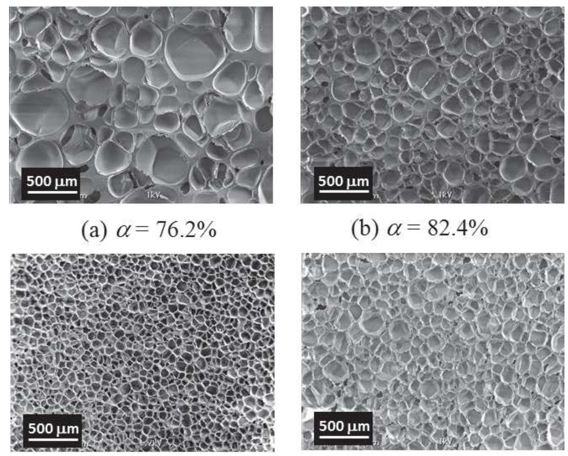
**ABSTRACT** – In this study, the effect of porosity on the dry sliding fiction of ethylene vinyl acetate (EVA) foams was investigated under different normal load conditions. The friction coefficient increased with increasing porosity under all of the normal load conditions. In addition, the contact area was estimated using a contact model considering elastic buckling of the cell walls. The friction coefficient was positively correlated to the estimated contact area divided by the normal load, indicating that adhesion friction increases with increasing porosity of EVA foams.

## 1. INTRODUCTION

Polymer foams are widely used in insulating materials, packing materials, and marine floating bodies, etc. [1]. Closed-cell structured ethylene vinyl acetate (EVA) foam is light and high cushioning and is thus used in running shoe midsoles. EVA foam with high friction could be used as outer sole materials for running shoes. Our previous study [2] demonstrated that the EVA foam blocks with higher porosity exhibited higher friction coefficient than non-porous EVA block, which was caused by an increase of contact area of the EVA foam blocks during sliding resulting from elastic buckling of the cell walls of the foams, i.e. elastic collapse [2]. Normal load will affect the elastic collapse area of EVA foam; however, the effect of porosity on the dry sliding friction coefficient of EVA foams is unclear under different normal load conditions. Thus, in this study, the effect of porosity on the friction coefficient under different normal loads was investigated.

## 2. METHODOLOGY

EVA foam blocks (10 mm × 10 mm × 5 mm) with different porosity ($\alpha$) values (76.2%, 82.4%, 85.9%, and 89.3%) were prepared. Figure 1 shows scanning electron microscopy (SEM) image of the surfaces of EVA foam blocks. Table 1 lists mechanical property of each block specimen. Sliding friction tests were performed using a linear-motion-type friction tester. Each EVA foam block was slid against a stainless-steel plate (JIS SUS304) with a surface roughness Ra = 0.02 μm. Normal load applied was 0.98, 1.96, 2.94, 3.92, and 4.9 N. The sliding velocity was 0.1 m/s. The sliding distance was 0.03 m.




(a) $\alpha$ = 76.2% (b) $\alpha$ = 82.4% (c) $\alpha$ = 85.9% (d) $\alpha$ = 89.3%

Figure 1 SEM images of EVA foam blocks.

Table 1 Mechanical property of EVA foam blocks.

| Porosity $\alpha$, % | 76.2 | 82.4 | 85.9 | 89.3 |
|---|---|---|---|---|
| Mean pore diameter $d$, μm | 279.1 | 140.8 | 91.1 | 117.6 |
| Density $\rho$, x10$^3$ kg/m$^3$ | 0.2 | 0.2 | 0.1 | 0.1 |
| Breaking strength $\sigma_T$, MPa | 2.1 | 1.6 | 1.6 | 1.1 |
| Breaking strain $\varepsilon_T$, % | 418.6 | 379.0 | 323.6 | 304.9 |
| Initial tensile modulus $E_T$, MPa | 4.9 | 3.2 | 3.6 | 0.6 |
| Initial compressive modulus $E_c$, MPa | 4.2 | 3.0 | 2.5 | 1.4 |

## 3. RESULTS AND DISCUSSION

Figure 2 depicts the effect of the porosity on the friction coefficient under different normal load conditions. The friction coefficients for the EVA foam blocks tends to increase with increasing porosity. The friction coefficient tended to decrease with increasing normal load for each EVA foam block.

The contact area observation using glass plate revealed that the anterior part of the block specimen was collapsed, thereby possibly revealing the disappearance of the pores on the surface. The contact area was estimated using the simplified analytical contact model considering the elastic buckling of cell walls of the foam, i.e., elastic collapse (Figure 3) [2]. When the contact pressure at the anterior part of the foam block excesses the elastic collapse stress $\sigma_{el*}$, the cell wall is collapsed and the effect of pores on the contact area is negligible. Thus, the length of the elastic collapse area in the $x$ direction, $l_c$, and the estimated contact area between EVA foam block and mating rigid surface $A_{est}$ are obtained as follows:

$$l_c = \frac{L}{2} - \frac{bL^3}{12F_x h}\left(\sigma_{el*} - \frac{W}{bL}\right), \qquad (1)$$

$$A_{est} = A_{collapse} + A_{no-collapse} = bl_c + b(l - l_c)\left(\frac{\rho^*}{\rho_s}\right), \qquad (2)$$

Where $b$ is the block width, $L$ is the block length, $h$ is block height after normal load applied, $W$ is normal load, $F_x$ is friction force. The $\rho^*$ and $\rho_s$ are the densities of EVA foam and EVA (900 kg/m$^3$), respectively. As shown in Figure 4, the estimated contact area of the portion without collapse ($A_{no\text{-}collapse}$) deceases with increasing porosity whereas that without collapse ($A_{collapse}$) increases with increasing porosity. As a result, the estimated total contact area tends to increase with increasing porosity of the foam (Figure 5) because of the increased elastic collapse area (Figure 4(b)).

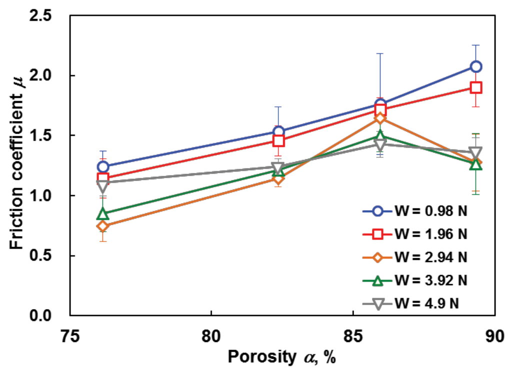



Figure 2 Effect of porosity on friction coefficient [3].

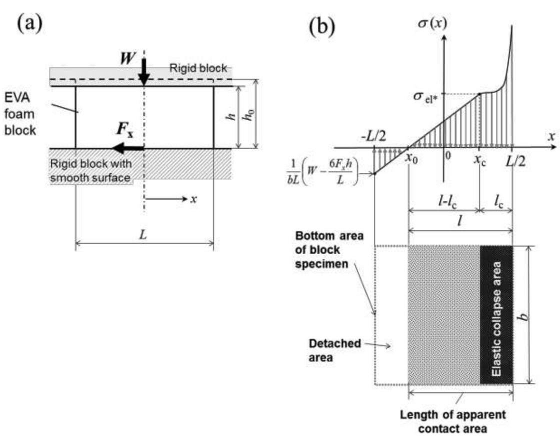
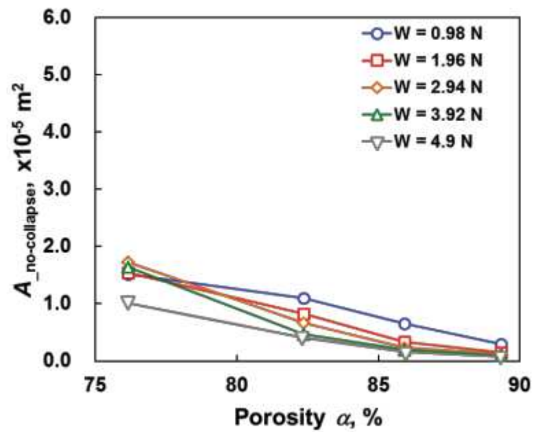



Figure 3 Schematic of (a) the simplified analytical model and (b) normal stress distribution as a function of the length of the block in the sliding direction and the apparent contact area [2].

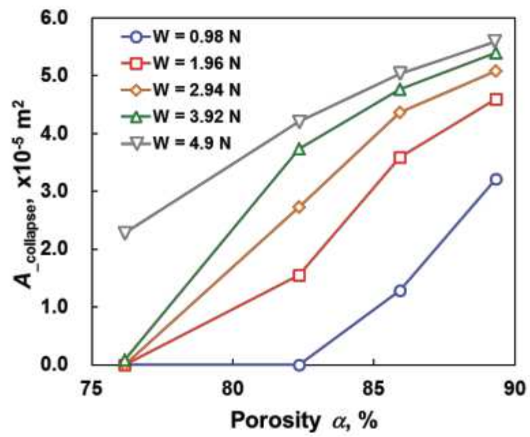
According to adhesion friction theory, the friction coefficient is expressed as follows:

$$\mu = \tau \frac{A_{est}}{W}, \qquad (3)$$

Where $\tau$ is shear strength at the interface. Figure 6 depicts the relationship between friction coefficient and $A_{est}/W$ values. As shown in Figure 6, the friction coefficient tends to increase with increasing $A_{est}/W$ values ($R$ = 0.86, $p$ < 0.001). These results indicate that the increase in the friction coefficient with increasing porosity under different normal load conditions was due to the increase in adhesion friction.




(a) $A_{\_no\text{-}collpase}$




(b) $A_{\_collpase}$

Figure 4 Effect of porosity on the estimated contact areas of the portion with and without collapse.

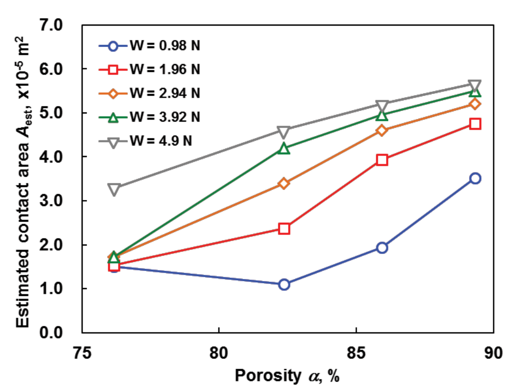



Figure 5 Effect of porosity on the estimated contact area [3].

## 4. SUMMARY

The results of this study demonstrate the significance of the unique deformation behavior of polymer foams, i.e., elastic collapse, on the increase of friction. This will contribute to the design of high-friction, light-weight shoe sole tread blocks fabricated using polymer foam blocks.

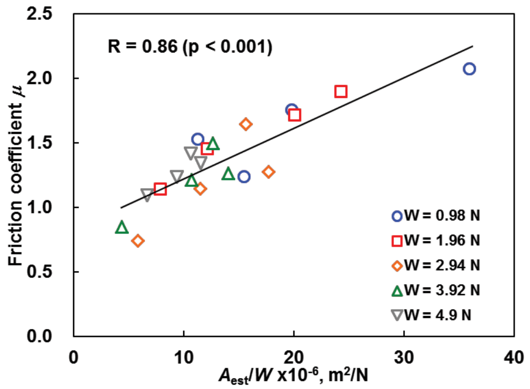



Figure 6 Relationship between $A_{est}/W$ values and friction coefficient [3].

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