**NOTE**

Tactile Texture of Cosmetic Sponges and Their Friction Behavior under Accelerated Movement

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Abstract: We evaluated the friction properties of five cosmetic sponges on artificial skin using sinusoidal motion-friction evaluation system. No significant difference was observed in the pleasant score of the five sponges when these sponges were rubbed on the skin surface. The sponges were classified into three groups based on their tactile feel. Their characteristic tactile textures were moist-soft-slippery, moist-dry-rough, and moist feels. The slippery feel was found to depend on the thickness of the sponge’s cell wall, its surface tension, and the change in friction coefficient in the dynamic friction process. These findings are useful in the design of cosmetic sponges.

Key words: cosmetic sponge, friction, tactile sensation, accelerated movement

1 INTRODUCTION

Durability, aesthetics, and ease of use in the application process are important requirements to consider while designing cosmetics1. The tactile feel is a complex sensation that changes the usability quite drastically. It involves several factors, and it depends on the frictional stimuli at the skin’s surface2. Some researchers have focused on the effects of the friction properties on the tactile feel during the application of cosmetic products. Horiuchi et al. showed that static and kinetic friction coefficients are not always the dominant factors in determining the comfort feel when subjects rub powder foundation with their fingers3. Sukigara et al. showed that the smooth feel of cosmetic sponges depends on the surface roughness, density, and mechanical properties of the sponge4. Yama-guchi et al. reported that, under slow sliding conditions, a high score for sensory pleasantness was obtained for cosmetic sponges with low friction resistances5. Bhushan et al. revealed that the friction coefficient and adhesion force of cosmetic cream depended on the aging time, cream film thickness, velocity, normal load, relative humidity, and temperature6.

The evaluation of the friction phenomena in make-up processes have previously been done under sliding conditions with constant speed. However, this condition deviates from real human behavior7–10. When a human touches an object, the sliding speed always changes because the processes are under nonlinear motion with acceleration. Nonlinear phenomena that cannot be described by the Coulomb–Amonton’s law ($F = \mu W$, $F$: friction force, $W$: vertical force, $\mu$: friction coefficient) can occur under such a complex motion. Recently, we developed a friction evaluation system where the speed varies sinusoidally with time to mimic the sliding behavior during cosmetic processes11.

In the present study, the friction force was evaluated using the sinusoidal motion-friction evaluation system. This force was measured by rubbing urethane artificial skin with commercially available cosmetic sponges. The tactile sensation, when the forearm skin surface was rubbed with a cosmetic sponge, was also evaluated. This was done to elucidate the relationship between friction and tactile sensation. The present study will be beneficial in the design process of cosmetic sponges.

2 EXPERIMENTAL PROCEDURES

2.1 Materials

We evaluated the sensory and physical properties of five cosmetic sponges, a to e. The sponges a, b, and d are made of polyurethane, while c and e are made of nitrile butadiene rubber and styrene butadiene rubber, respectively.
Figure 1 shows the scanning electron microscope (SEM) images of sponges a to e (SU8000, Hitachi, Tokyo, Japan). Large cell number and thin cell walls were observed in sponge a, while thick cell wall was observed in sponges b, c, and e. Table 1 shows the shape and physical properties of sponges a to e. The dimensions of the sponges are 52–73 mm in length, 40–53 mm in width, and 8–12 mm in thickness. The hardness is 38–73 HF°, the number of cells per unit area is 134–826, and the thickness between the cells is 15–39 μm. The hardness (HF°) was measured by the method described in JISK6253. The evaluation machine was an ASKER Durometer Type F (radius of compression surface = 25.2 mm, compression pressure = 500 g, KOBUNSHI Co., Ltd., Kyoto, Japan).

### Table 1 Physical properties of cosmetic sponges.

<table>
<thead>
<tr>
<th>Material</th>
<th>Length / mm</th>
<th>Width / mm</th>
<th>Thickness / mm</th>
<th>Density / gcm⁻³</th>
<th>Hardness / HF°</th>
<th>Cell number 950 × 1300 μm</th>
<th>Cell wall / μm</th>
<th>Surface Tension / mNm⁻¹ (20°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>52</td>
<td>45</td>
<td>9</td>
<td>0.142</td>
<td>52</td>
<td>211</td>
<td>27.9</td>
<td>37.65</td>
</tr>
<tr>
<td>b</td>
<td>73</td>
<td>52</td>
<td>12</td>
<td>0.130</td>
<td>38</td>
<td>270</td>
<td>39.2</td>
<td>37.65</td>
</tr>
<tr>
<td>c</td>
<td>72</td>
<td>53</td>
<td>12</td>
<td>0.117</td>
<td>46</td>
<td>134</td>
<td>33.4</td>
<td>51.65</td>
</tr>
<tr>
<td>d</td>
<td>62</td>
<td>40</td>
<td>9</td>
<td>0.108</td>
<td>53</td>
<td>826</td>
<td>15.4</td>
<td>37.65</td>
</tr>
<tr>
<td>e</td>
<td>52</td>
<td>45</td>
<td>8</td>
<td>0.172</td>
<td>68</td>
<td>256</td>
<td>34.2</td>
<td>44.25</td>
</tr>
</tbody>
</table>

2.2 Tactile evaluation

Tactile evaluations were performed on twenty female subjects aged 22–25. The evaluations were done in a quiet room at 298 ± 1 K with a relative humidity was 50 ± 2%. In order to eliminate the order effect, the subjects evaluated five sponges randomly. Subjects washed the inside of the forearm with a commercial liquid hand soap before each evaluation. The experimenter rubbed the inside of the forearm of the subjects 10 times with a cosmetic sponge (Fig. 2). A blackout curtain was placed between the subjects and the experimenter. Each subject rated the sensory pleasantness of the sponge’s tactile sensation on a visual analogue scale; their evaluated score was marked as a posi-
The pleasantness sensory score was estimated by the length of this line from the end point. Specifically, the score was measured as a portion of the distance between the end labelled "dislike" and the marker. In this manner, "like" and "dislike" were assigned to a score of 10 and 0, respectively. When twenty subjects were rubbed with sponges, they described the sponge texture using 27 different Japanese words. These descriptions were classified into 10 tactile dimensions, such as soft, hard, dry, moist, slippery, sticky, smooth, rough, cold, and hot. All evaluations were conducted according to the principles expressed in the Declaration of Helsinki, and the responsible party at Yamagata University confirmed that the ethics and safety of the present test were acceptable.

3 RESULTS

3.1 Tactile texture of the cosmetic sponges

Figure 4 shows the pleasant scores of each sample. Sponge d scored the highest of 8.3 ± 1.3 (average ± standard deviation), while that of e was the lowest at 5.4 ± 2.5. The statistical difference could not be obtained between these scores due to large deviation. The selected words made up ten groups based on their tactile dimensions. The dendrogram obtained by hierarchical cluster analysis using the Ward Method is shown in Fig. 6. The sponges could then be classified into three main categories based on their major tactile textures. We determined the characteristic tactile texture when the score of the feeling was 60% or more. The characteristic tactile texture of group I consisting of sponges a and d is the moist, soft and slippery feels. The characteristic tactile texture of group II consisting of b is the moist feel. The group III consisting of sponges c and d does not have the characteristic tactile texture. The relatively strong textures are moist, dry and soft feels. These results show that tactile texture is unique for each sponge.

3.2 Friction properties

Figure 7 shows a typical profile of the temporal change of the friction coefficient when an artificial skin is rubbed with sponges d. Black and dotted lines show the temporal profiles of friction coefficient and the velocity, respectively. Here, \( T/T_0 \) is the ratio of time after the start of sliding to

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T/F_0 = 0.98 \text{ N}, \quad \text{round trip time} \ T_0 = 3 \text{ s}, \quad \text{rotation speed of an eccentric disk } 2.1 \text{ rad s}^{-1}, \quad \text{and maximum velocity of the sine motion } 20 \text{ mm s}^{-1}. \]
Figure 8 shows the average of the static friction coefficient, the kinetic friction coefficient for three friction evaluations, and the change of the friction coefficient. When the artificial skin was rubbed with d, a static friction coefficient of \(-1.74\) was observed at \(\frac{T}{T_0} = 0.129\). After that, the kinetic friction coefficient became similar to the static friction coefficient. In many cases, the friction resistance reaches a maximum at the moment of
sliding and settles into a smaller kinetic friction process through relaxation processes. All sponges in this study showed a characteristic profile with extremely small variations between their kinetic and static frictions (Fig. 7). This suggests that the cosmetic sponges slide smoothly over the artificial skin surface. In the sponge sliding process, a delay phenomenon occurs when the friction force is slightly delayed with respect to the corresponding movement of the sponge. This phenomenon is not observed for hard materials such as metals and metal oxides, and only a very slight delay of about δ = 0.007 has been observed on the surface of the polymer resin (11). In this study, δ of 0.06–0.08 was observed because the cosmetic sponge is soft and thick. The friction force is not apparent for a short time because the distortion is absorbed by the deformation of the sponge even if the contact probe starts to move.

3.3 The relationship between the tactile texture, physical properties, and friction properties

We analyzed the relationship between the tactile texture, physical properties, and friction characteristics of the five cosmetic sponges. The characteristic tactile textures of the three groups, the group I, II and III are caused by the surface tension, thickness of the cell wall, and the change of the friction coefficient of the kinetic friction process. Figure 9 shows the relationship between the change of friction coefficient, cell wall thickness, and surface tension. Here, the change of the friction coefficient is the difference between the minimum friction coefficient and the maximum friction coefficient in the kinetic friction process. The change of the friction coefficient was small for the group I, whose cell walls are thin and surface tensions low. Conversely, the change was large for the group III, whose cell walls are thick and surface tensions large. These results indicate that the change of the friction coefficient increases for the cell walls that are thick and for surface tensions that are large. In addition, a clear negative correlation was observed between the change of the friction coefficient and the slippery feel (Fig. 10). The group III with a large change of friction coefficient showed the lowest slippery feel. The change of friction coefficient varies with the surface tension and the thickness of the cell wall because the contact area between the sponge and the skin is large when the cell wall is thick and the adhesive strength is strong when the surface tension is high. These changes can cause high frictional forces during the rubbing process. The cosmetic sponge is categorized as a viscoelastic soft material consisting of a viscosity term and an elastic term.

4 CONCLUSIONS

The relationship between tactile sensation and the friction properties of five cosmetic sponges were examined. Commercially available cosmetic sponges have distinct tactile sensations that can be classified into three groups. When these sponges were rubbed through a sinusoidal motion, a delay phenomenon, δ, was observed, and the friction force was observed to be slightly delayed in rela-
tion to the movement of the sponge. Additionally, the change of the friction coefficient during the kinetic friction process varied for each sponge. It was confirmed that the change of the friction coefficient varies depending on the surface tension and the thickness of the cell wall, affecting the slippery feel. These results are important in designing the cosmetic sponge and controlling the sensory perception thereof.

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References