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The microtextured plastic moldings to control human tactile sense: The texture effect enhancement due to apical shape and material frictional properties

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ABSTRACT

The purpose of this study is to develop a plastic molding with a distinguishing tactile character for various industrial applications. In the present paper, we investigated the effects of the apical shape of the texture and the frictional properties of the plastic material on the tactile sense of the textured plastic molding in order to enhance the texture effect. Based on the analyses conducted, it was found that both the apical shape and the material frictional properties affect the particular tactual sensation of the plastic molding. The “Uneven” and similar trend sensations, which are mainly dominated by the fluctuation of friction, were dependent on the apical shape due to the sticking characteristics of the fingerprint. The strength of these sensations was caused by the sharper apical shape. The “Sticky” sensation was dominated by the complex effect of the fluctuation of friction and the frictional properties of the plastic material. The larger texture effect elicited for “Slick” sensations was obtained at round and sharp textures with a pitch of 120 μm. The enhanced texture effect of material frictional properties was observed at the apical shapes with large contact area, and it was obtained at the round texture. However, flat texture elicited a similar sensation to that elicited by the nontextured surface as a result of the small texture effect and large contact area. These results indicate that control of the apical shape and material frictional properties is effective in enhancing the texture effect of the plastic molding surface.

1. Introduction

Plastic materials are used in various industrial fields, including automobiles, office automation equipment, cellular phones, and cameras because of their significant production advantages. However, the plastic has a distinctive material character in regard to the visual and tactile senses, and in this respect, it is sometimes regarded as inferior to metals, fabric, and other materials. The plastic surfaces in these fields are generally textured by etching at a millimeter scale in order to improve the material qualities to enhance these senses. This is because these sensual features are important, especially for products with high added value.

Recently, there has been considerable interest in a variety of new functional surfaces that are induced by micro- or nanoscale surface structuring [1]. These techniques enable us to control various surface functions, including tribological [2–4], optical [5], and material properties [6]. This method is also effective in improving the tactual sense of plastic moldings. In regard to everyday human usage, functional surfaces have been successfully applied to bathroom floors and arm rails to prevent slipping [7]. Several research studies conducted for the evaluation of human tactile sense have been reported. These research studies used grain [8] and blasted surfaces [9] with random shapes. Therefore, the tactile senses of specified and defined texture shapes, with sizes ranging from several micrometers to several hundreds of micrometers, have not been investigated.

The purpose of this study was to develop a plastic molding with a distinguishing and characteristic tactile pattern utilizing the surface texturing method. We have previously fabricated plastic moldings at the microscale and submillimeter scale texture, and investigated the effect of the texture shape on human tactile senses using multivariate statistical analyses and its mechanism in relation to the physical properties [10–12]. We found a significant change in sensation resulting from the microscale textures. Varying the texture pitch at approximately 100 μm resulted in significant changes in the sensations. These sensory properties depended more on the

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pitch rather than on the height of the features. The physical property investigation revealed that the fluctuation of the friction was related to the sensations rather than to the friction coefficient, surface roughness, or deflection. This fluctuation was caused by the intrusion of the surface features into the grooves of the fingerprint. Therefore, the texture pitch was the most significant factor determining the intrusion of the apical surface patterns into the grooves of the fingerprint pattern. The friction coefficient affects only at the nontextured surface for some sensations. The values of the surface roughness and deflection did not strongly affect the sensation.

In these experiments, we fabricated only triangle-shaped textures with sharp apical shapes. The texture of the apical shape is the only area contacting the human finger while rubbing the texture, and therefore constitutes an important factor for the determination of the tactual sense. In addition, the material frictional property of plastic is also a dominant factor that can enhance the texture effect.

In this paper, we investigated the effect of the apical shape of the texture on the tactual sense. Three-types of the apical shapes were fabricated and these effects were investigated using sensory evaluations. In addition, the effects of material frictional properties were also investigated using plastic materials with different frictional properties in order to enhance the texture effect. The physical properties of these textured surfaces were evaluated, and the mechanism causing the changes in the tactual sense was also investigated.

2. Texture fabrication on plastic moldings

Plastic moldings (35 mm × 35 mm × 1 mm) with grooved textures were used in the experiments. The texture size ranged from several tens of micrometers to several hundred of micrometers. Two types of the polypropylene (PP) materials were used for the fabrication of the plastic moldings in order to investigate the effect of material frictional properties on the tactual sense. One of them is the standard friction PP material (MF47C, Prime Polymer Co., Ltd.) and the other is the low friction PP material (MF18R, Prime Polymer Co., Ltd.). Hereafter, these materials will be called "normal friction" and "low friction" materials, respectively. These materials have different frictional properties but similar hardness. The hardness of the normal and low friction materials were HRR100 and HRR110, respectively. The friction coefficients of the normal and low friction materials against itself, measured by sliding test, were 0.37 and 0.08, respectively. Aluminum alloy A2017 was used for the molds because of its free machinability for texture fabrication rather than for its wear resistance. The textures were fabricated by transcription from the aluminum molds to the plastic materials.

The textures were fabricated by an ultraprecision cutting and a subsequent vacuum hot press method. The aluminum mold material was mounted on an ultraprecision cutting machine (FANUC Corporation, ROBONANO α-0*i*B) equipped with a shuttle unit model B [13], and a mirror-finished surface was prepared using a rounded tool. The resulting surface roughness was Rz = 0.04 μm. The surface was then machined via a high-speed shaper technique using various apical shapes of a single-crystal diamond tool with an apical angle of 90°. In this way, a grooved texture was fabricated on the aluminum mold surface. The machined mold and plastic pellets were mounted in a vacuum hot press machine (Imoto Machinery Co., Ltd., IMC-199A), and evacuation commenced. After the evacuation was completed, the texture on the mold was transcribed to a plastic surface by vacuum hot pressing, and a plastic molding with a grooved texture was fabricated after demolding.

Table 1 lists the texture shapes fabricated in this experiment. Fig. 1 shows schematic diagram of the texture shape. Sixteen species of textures with various apical shapes, pitches, heights, and materials were fabricated. Samples 1 and 2 had a nontextured surface, and they were fabricated by transcribing the pretreated surface, with different PP materials. Samples 3–16 had textured surfaces with various shapes and materials. Three types of apical shapes were fabricated. The first was a rounded apical shape with a radius of 20 μm (samples 3–10). The second type included sharp apical shapes (samples 11–13), which were also used also in our previous study [10]. The third type had a flat area with a width of 40 μm on the apex (samples 14–16). The apical angle of all textures was 90°. Hereafter, these apical shapes of the textures will be referred to as round, sharp, and flat textures, respectively. The texture shape was determined by the tool shape, and the resultant texture pitch was twice as long as the height at the sharp texture. The heights of the round and flat shapes were 8 μm and 20 μm lower compared to the sharp shape. Four pitch and height types were fabricated at the round texture, and the effects of these parameters were also investigated.

Fig. 2 shows a mold and the plastic moldings of PP with normal friction fabricated by ultraprecision cutting and vacuum hot pressing. A grooved sharp texture with a pitch of 120 μm and a height of 60 μm (sample 11) was fabricated on the mold surface, as shown in the scanning electron microscopy (SEM) image of Fig. 2(b). The top and bottom angles were both 90° due to the tool shape. Round and

Table 1
Specification of textures used for sensory evaluation.

Sample no.	Material	Texture shape	Pitch (μm)	Height (μm)
1	Standard fric.	Nontextured		
2	Low fric.	Nontextured		
3	Standard fric.	Round (radius of apex: 20 μm)	40	12
4			120	52
5			200	92
6			400	192
7	Low fric.		40	12
8			120	52
9			200	92
10			400	192
11	Standard fric.	Sharp	120	60
12	Low fric.		120	60
13			400	200
14	Standard fric.	Flat (width of apex: 40 μm)	120	40
15	Low fric.		120	40
16			400	180

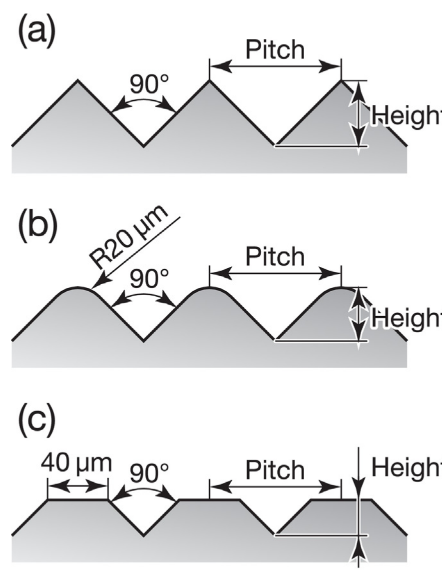

Fig. 1. Schematic diagram showing (a) sharp, (b) round, and (c) flat textures.