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Transparent Tactile Feeling Device for Touch-Screen Interface

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Abstract

We propose a transparent tactile feeling input device on the touch-screen interface, which provides actual keystroke and tactile key feeling without preventing the function of the touch-screen interface. Without using mechatronics elements such as force sensor or actuators, the device can adapt to the touch-screen interface used in general. In order to realize tactile feeling of clicking, we referred to a specific shape of the conventional switch in design process, and formed structure of the input device with the transparent silicone elastomer. Consequently, the experiment shows transparent haptic device realized click feeling on the touch-screen display.

Key Words: Human Machine Interface, Tactile Feeling, Touch-Screen Interface, Switch

1 Introduction

Importance of interfaces has been recognized along with development of computers and robotic systems [1][2]. Recently we are getting more opportunity to see a display outside the office or home to operate computers, service machine on a street corner, for example ATM machine, ticket vending machine, car navigation system, mobile devices such as PDA, and so on. Most of them are operated by touching a display. At present, a touch-screen interface is commonly used. A touch-screen interface is easy to use and user-friendly to operate the system outside the office or home compared with the other input device such as a keyboard or a mouse, which is basically designed for operation of computers by putting it on the flat table.

However, the touch-screen interface has some disadvantages such as lacking tactile feedback when users push switches on the screen, since these are just virtual switches that are displayed on it. It becomes one of worrying factors for users to confirm acceptance of their key input just by sounds or visual effects. The importance of tactile sensation has been recognized, as described in the dictum "What is heard is forgotten, what is seen is memorized, and what is touched is understood [3]." Various tactile feel or force displays have been developed so far to provide haptic feedback to the operator, especially in virtual reality environments in order to enhance reality. There have been proposed several haptic devices to display virtual force [4]-[7]. They used the structure of linkage with force sensor and electric motors. These motors generate resistance force when operators touched the virtual objects. Operators can feel much reality when they use the Head Mount Display (HMD)[8]. There is another way to realize the haptic device using surface of pins [9]. Pins are moved by the piezoelectric actuators to express two-dimensional haptic images. However those haptic devices are held by the operators constantly when they use such devices. These interfaces are not suitable for immediate or quick use. When we think about the interface in our lives, it should be simple and easy for beginners or elders to use without hesitation.

Purpose of our study is to make the human-machine interface more effective in our lives. Human-robot interactions by touching are integrated with the other methods, such as speech, vision, and so on [10]. In the future, tactile feeling would become one of the most useful functions for human-robot interactions.

In this paper we propose a haptic display, which provides stroke and click feeling for users to operate virtual switches on the touch-screen interface. Using transparent materials and solvent, the system would not lose its usefulness as the touch-screen. Tactile feeling is provided as a new function of the touch-screen interface. Without using mechatronics elements such as force sensor or actuators, it can be applied to the touch screen interface easily for general use. At present, a tactile feeling touch-panel display is marketed as "Force Feedback Touch Panels"[11] from SMK Corporation. It utilizes vibration of the piezoelectric elements to give tactile feelings. In this paper, we utilized buckling and keystroke of the real structure to realize tactile feel of clicking.

2 Design

Tactile feeling of clicking is realized by buckling of the structure. In the mobile phone metallic domes are placed under the buttons to make tactile feedback. And soft rubber built in keyboard keys also feed back tactile feeling. Those feedback enables us to input letters easily and quickly in touch-typing. Although the characteristic of the tactile feeling is different depends on its materials, most of switches are made in almost the same shape.

So we designed the shape of the switch structure like upside down bowl shape copying a specific pattern in popular use. To feel tactile feeling at any place on the display, we expanded the shape of the key top area and designed its figure in a hexagon to fill the whole surface. The tactile feeling device consists of these switch arrays.

In order to use the device on the display, it must be transparent. Switch structure is made using transparent material. We use silicone elastomer as switch structure material which has high clarity (over 88% in transmission factor). However, no matter how clear material we use, there is difference of the reflective index between the material and air. Because of the parallax or surface roughness of the model, the images displayed on the screen would get the distorted vision. To solve this problem, we use the same reflective index of solvent all together. In this case, the reflective index of silicone elastomer is about 1.41, so we choose glycerin as solvent whose reflective index is 1.4095 (Table 1). Liquid solvent fills up void space of the structure and plugs the micro asperity on the silicone surface. In this way, we can eradicate reflective effects.

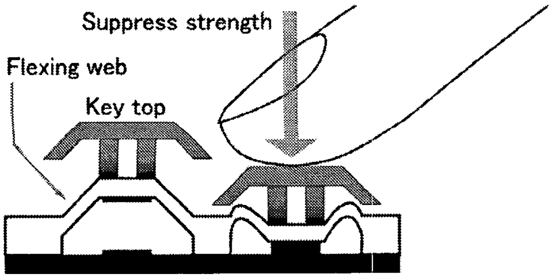


Figure 1. Upside down bowl structure

Table 1. Reflective index and viscosity of materials

Material	Reflective index	Viscosity (m$Pa \cdot s$)
Silicone	about 1.4	-
Air	1.000	-
Glycerin	1.409	106.9
Methanol	1.329	6.2
Etanol	1.362	12.0
Aceton	1.359	3.2
Water	1.333	10.1

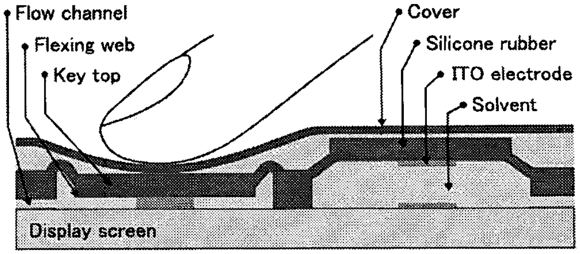


Figure 2. Concept of the device

We designed to use liquid glycerin as solvent, so we have to allow the solvent to escape when the array is pushed. Flow channels are put in all side of arrays. To ignore flow resistance of the solvent, flow passage area was designed using a model of a dashpot [12]. Elastic coefficient of fluid is given by

$$c = 8\pi\mu l \frac{A^2}{a^2} \tag{1}$$

where A is the piston section area, a is the flow passage area, l is the depth of flow passage, and μ is the viscosity of liquid (See Table 1 and Fig.3). And the resistance force is given by

$$F = c(dx/dt) \tag{2}$$

If the user completes the process of clicking within 0.1 second and $a = 1.0 \times 0.3mm^2$, then flow resistance force becomes about 0.02 N. This is much smaller than 0.8 N, which is the reaction force of ordinal touch switches. So we can evaluate the touch feeling without taking account of the flow resistance.

In order to cover the display, we made 70 mm square and 2.5 mm high seat-like device that contains 48 switch arrays. Figure 4 shows the design of the array.

To confirm on-off action of the switches, we attached Indium Tin Oxide (ITO) thin film as electrode under the key top. ITO is transparent conductive material that is embedded in electronic and opt-electronic devices due to its excellent properties of high conductivity ($10^4 \Omega^{-1} cm^{-1}$) and high transparency (85-90%) [13]. We embedded ITO thin film on the silicone elastomer structure by sputtering.

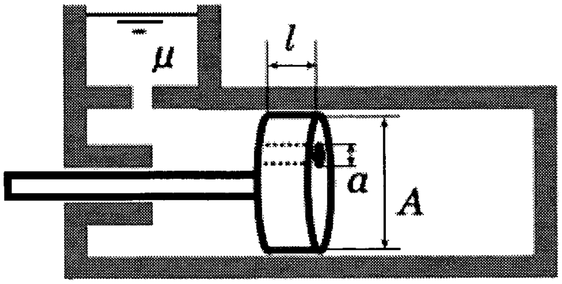


Figure 3. Dashpot model

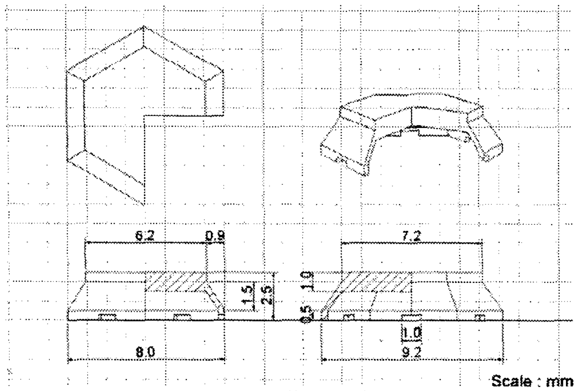


Figure 4. Modeling of the array

3 Fabrication

At first, we tried various shapes. To make some prototypes, we used the three-dimension (3D) modeling device, which can produce 3D objects by laminating solid wax material. The heated wax jetted out from the valve nozzle creates 50 μm thick layers. The shape can be redesigned easily by the Computer Aided Design (CAD) system. We made some molds of structure which has only 7 arrays on surface. We tried some types of key top shape or some depths of key stroke to know which shape is suitable for the silicone elastomer. The last shape was fixed from qualitative assessment of these prototypes.

After the design of the array fixed as Figure 4, we changed the process to make large size structure model. Small surface area model like prototype can be made from the wax mold which is produced by the 3D modelling device. However, in order to expand surface area to make the sheet like device, silicone structure model can't be peeled off from the mold in the previous process because of lacking of flexibility of wax molds. So we arranged the process as shown in Figure 5. Initially upper and under surfaces of the structure model that designed in the CAD system are made in several. Using a flexible soft rubber elastomer, which has 230% modulus of elasticity in tension, we formed female molds. After that, we made the surface of molds hydrophilic by oxygen plasma treatment in order to peel off the model easily. At the last, the transparent silicone elastomer was poured between the molds. It takes about 24 hours at 23 degrees to shape the silicone structure model. Furthermore, the silicone elastomer molds have enough permanence, so we can make the structure model many times with a pair of molds. It leads to better productivity. Additionally, ITO electrode is attached under the key top by spattering. Figure 6 shows a large size (70 mm square) silicone structure model which is made in the process shown in Figure5.

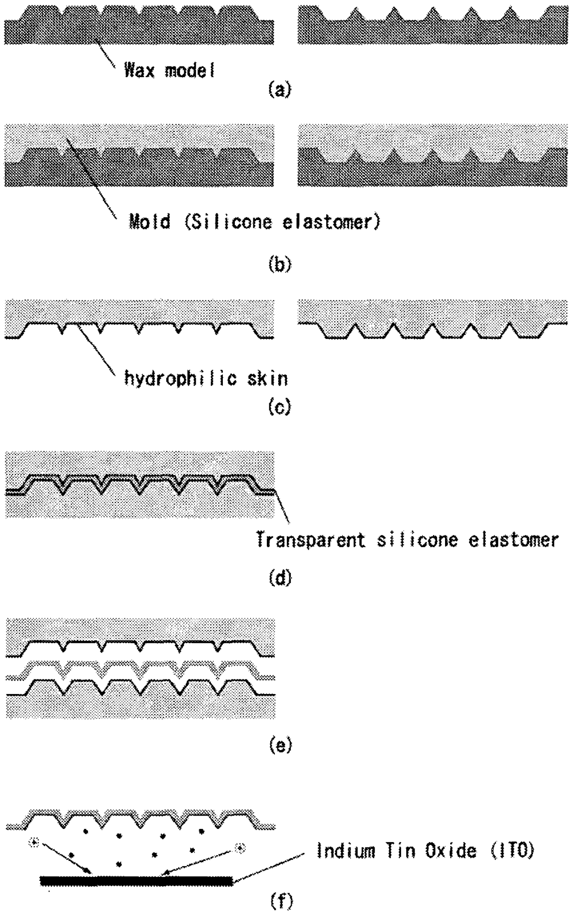


Figure 5. Fabrication process flow: (a) 3D wax model (b) female mold fabrication (c) surface treatment in hydrophilic (c) pouring of silicone elastomer (d) removal of molding (f) ITO electrode spattering

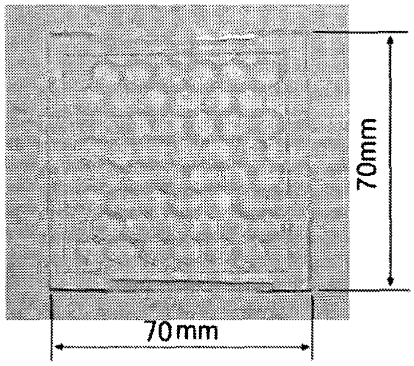


Figure 6. Silicone structure model

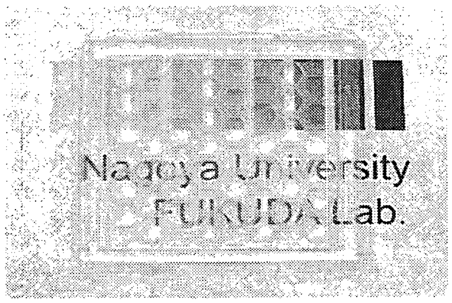
4 Experiment

4.1 Visibility of the device

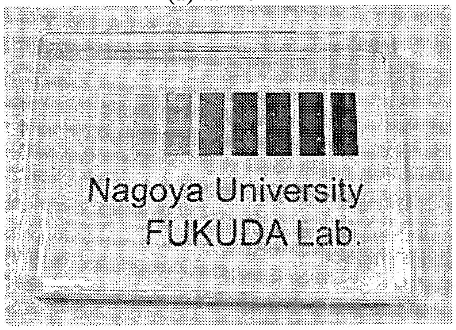
The transparent switches arrayed model is shown in Figure 7(a). It has a lot of parallax displacement and surface roughness in the air, so the visibility was not suitable for using on the touch-screen display. We filled up the space between the model and printed image with the transparent solvent: glycerin, whose reflective index is same as that of silicone elastomer. The surface of the model is also covered with the solvent and a flat seat which is made of the same silicone elastomer to equalize the reflective angle. Figure 7(b) shows the visibility of the device with the solvent and the flat cover seat. In this case, we can see the printed image clearly without getting distorted. Liquid solvent can fill up any spaces no matter how complex structure is. So we can extend freedom of structure design.

4.2 Tactile feeling of the device

To evaluate tactile feeling of the device, we graphed the relation between keystroke and reaction force at the time. We used displacement gauge to hold keystroke every 0.05 mm, and measured the weight as reaction force on the key top by digital scales. We call the relation of reaction force and stroke drew on chart as Force-Stroke curve (F-S curve). Generally F-S curve indicates nonlinearity because of the buckling phenomenon of the structure, it is said that the larger difference between local maximum and minimum value of reaction forces, the better tactile feeling user feels. Structure of the other switch is different in accordance with the intended uses. From its F-S curve we can evaluate the characteristics of tactile feelings quantitatively.



(a) In the air



(b) In the solvent (glycerin)

Figure 7. Visibility of the device

Figure 8 shows the F-S curve of the structure model we made. We measured three different points. The difference between the maximum and minimum reaction force is about 0.2 N. This difference is at the same level as the other upside down bowl type switch structure made of silicone rubber, for example, embedded in keyboard.

Figure 9 shows the F-S curve of the device including solvent and top cover. In this case, the characteristics of these F-S curves are changed by the thickness of the top cover. We tested some covers in different thickness using the same silicone material. Thick cover bended with the surrounding switch arrays when the operator pushed one array. So, when the F-S curve becomes smooth, it means the decrease of tactile feelings. Thin film excels in flexibility, but we may as well say that thin film has risk of break.

Additionally we tried another type of structure. In this new design, cross-section surface of the model is same as the previous one. But the surface area of switch key top is designed for about one-quarter of the size of previous one. Fabrication process is same as shown in Figure 5.

As a consequence, we have F-S curve of this model shown in Fig.10. The F-S curve in a single array draws nonlinear curve. From this result, we confirmed tactile feeling is given by the small array.

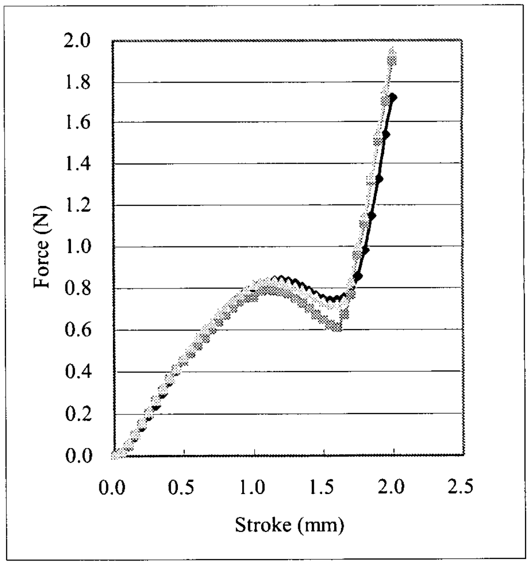


Figure 8. Force-Stroke curve

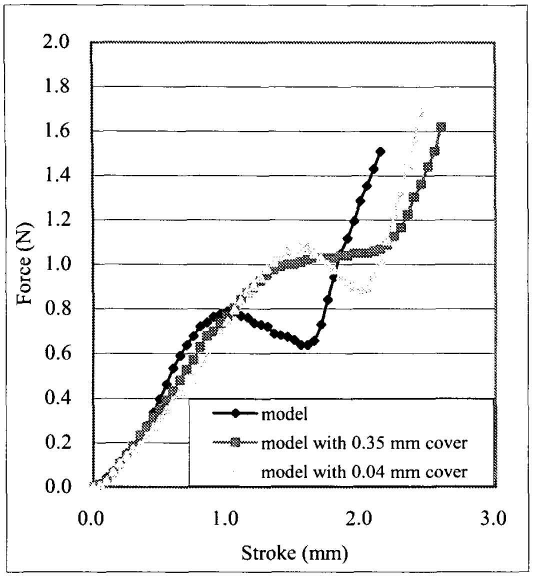


Figure 9. Force-Stroke curve (Including solvent and top cover)

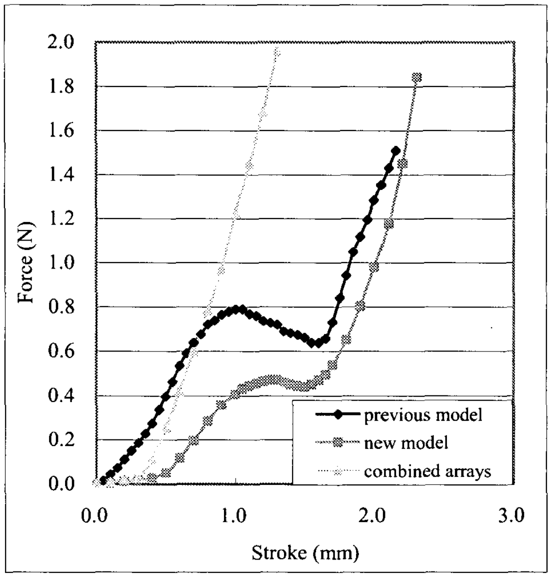


Figure 10. Force-Stroke curve (Comparison between the previous and new model)

Actually, however, the feeling of clicking wasn't felt clear compared to the previous model by human finger. Because of the size of finger, some of the small arrays are pushed in bulk. Since the buckling of the structure doesn't occur at the same instant, user couldn't feel tactile feeling of clicking. Figure 10 shows the F-S curve which evokes human touch. We used 10 mm square soft silicone material to push the switches, and measured total reaction force from the switch structure. In this case, the F-S curve drew a straight line like an elastic body.

4.3 ITO electrode

To confirm on-off action of the switches, we attached Indium Tin Oxide (ITO) thin film to make electrodes by spattering. Figure 11 shows ITO thin film attached on the silicone structure model (7 arrays, small size model). Thickness of formed ITO thin film is about $0.7\mu m$ in calucuration. The sheet resistance is $185\ k\Omega/square$. Although, the contact of ITO electrode was confirmed in spite of its high resistance, we need improvement in supattering conditons or redesign of electrode.

4.4 Evaluation on a touch-screen interface

We did experiment on the tactile feeling of the switch by putting it on the general touch-screen display. The touch sensor of the touch panel is used instead of ITO electrode. The size of the screen is 151×111 mm and the resolution is 640×480 pixels. We put up 32×24 mm square 9 buttons on the screen. Figure 12 shows outline of the experiment. User could operate the buttons with feeling of the buckling of transparent switch structures. In some points, for example at the array boundary, we couldn't feel buckling clearly. We need improvements in equalization of touch feeling.

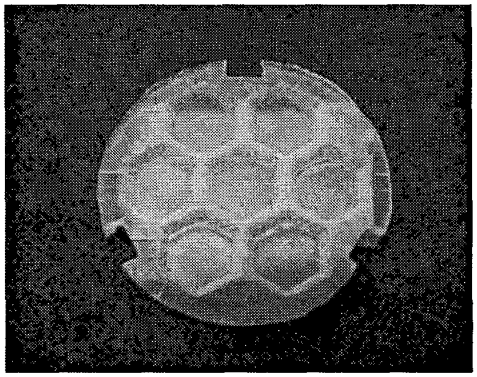
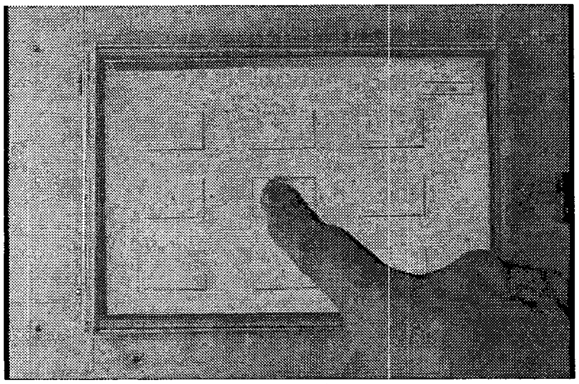


Figure 11. ITO electrode

5 Conclusion

A tactile feeling device on touch-screen has been proposed. Upside down bowl shape structure yields click feelings, and it was confirmed through the Force-Stroke curve. Using a transparent silicone material and solvent of the same reflective index, we can realize transparent switch. Transparent ITO electrode is attached to confirm inputs. The device can provide keystroke and click feeling to users who operate the touch-screen interface.



(a) Top view

(b) Side view

Figure 12. User experiment with the device on the screen

6 Future works

The proposed device is simple and adapts to the touch-screen interface easily. However, since users have their own preferences in touch feelings, we should evaluate usability of the switch. Moreover, endurance and reliability tests are needed for practical use.

7 Acknowledgments

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8 Reference

[1] M. Weiser "Some Computer Science Issues in Ubiquitous Computing", *Association for Computing Machinery Communications of the ACM*, Vol.36 Issue7, pp74-83, 1993

[2] Dearden AM, Harrison MD, "Impact and the design of the human-machine interface", *IEEE Aerospace and Electronic Systems Magazine*, Vol. 12, No. 2, pp19-25, 1997

[3] M. Yamaoka, K. Yamasaki, H. Tanaka "Extracting Relational Constraints among Objects with Haptic Vision in Support of Automatic Construction ", *Electronics and Communication in Japan, Part3*, Vol. 86, No. 11, 2003

[4] J. Dionisio, V. Henrich, U. Jakob, A. Rettig, R. Ziegler "The Virtual Touch: Haptic Intergaces in Virtual Environments", *Comput. & Graphics*, Vol. 21, No. 4, pp. 459-468, 1997

[5] T. Yoshikawa, A. Nagura "A Touch/Force Display System for Haptic Interface", *Presence-Teleoperators and Virtual Environments*, Vol.10, Vol.2, pp225-235, 2001

[6] M. Kawai, T. Yoshikawa "Haptic Display With an Interface Device Capable of Continuous-Time Impedance Display Within a Sampling Pariod", *IEEE ASME Transactions on Mechatronics*, Vol. 9, No. 1, pp. 58-64, 2004

[7] N. Ando, P. Korondi, "Development of Micro-manipulator and Haptic Interface for Networked Micromanipulation", *IEEE ASME Transactions on Mechatronics*, Vol. 6, No. 4, pp. 417-427, 2001

[8] Marc O. Ernst, Martin S. Banks and Heinrich H. Bulthoff "Touch can change visual slant perception", *Nature Neuroscience,* Vol.3, No.1, ppp69-73, 2000

[9] M. Shimojo, M. Shinohara, Y. Fukui "Human Shape Recognition Performance for 3-D Tactile Display", *IEEE Transaction on Systems, Man, And Cybernetics-Part A: Systems and Humans*, Vol.29, No.6, 1999

[10] S. Kristensen, M. Neumann, S. Horstmann, F. Lohnert, A. Stopp, "Tactile Man-Robot Interaction for an Industrial Service Robot", *Sensor Based Intelligent Robots Lecture Notes in Computer Science*, Vol. 2238, pp177-194, 2002

[11] SMK Corporation, "Force Feedback Touch Panels", http://www.smk.co.jp/

[12] JSME Mechanical Engineer's Handbook, B1: Machine Elements and Tribology, pp151, 1985 (in Japanese)

[13] C. P. Udawatte, K. Yanagisawa "Sintering of Additive Free Hydrothermally Derived Indium Tin Oxide Powders in Air", *Journal of Solid State Chemistry*, Vol. 154, No. 2, pp 444-450, 2000