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Ergonomics Designs of Aluminum Beverage Cans & Bottles

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Abstract. This paper introduced the finite element analyses into the ergonomics designs to evaluate the human feelings numerically and objectively. Two design examples in developing aluminum beverage cans & bottles are presented. The first example describes a design of the tab of the can with better finger access. A simulation of finger pulling up the tab of the can has been performed and a pain in the finger has been evaluated by using the maximum value of the contact stress of a finger model. The finger access comparison of three kinds of tab ring shape designs showed that the finger access of the tab that may have a larger contact area with finger is better. The second example describes a design of rib-shape embossed bottles for hot vending. Analyses of tactile sensation of heat have been performed and the amount of heat transmitted from hot bottles to finger was used to present the hot touch feeling. Comparison results showed that the hot touch feeling of rib-shape embossed bottles is better than that of cylindrical bottles, and that the shape of the rib also influenced the hot touch feeling.

INTRODUCTION

Structural optimization methods based on the finite element analysis have been applied to search the optimum shape and dimensions of the aluminum beverage cans & bottles [1, 2]. With the quality of human life being improved, it is becoming necessary to design containers universally based on ergonomics evaluation that considers psychological, physiological, anatomical affects. Human-friendly, ease-of-use and comfort are being expected in the development of containers to enhance the quality of human life [3, 4]. Developments of aluminum beverage cans & bottles require ergonomics evaluation such as tactile sensation of fingertip to be taken into account. Ergonomics designs can be found in many literatures [5, 6]. The physical, cognitive and emotional comfort of the consumers should be considered to create an optimal human-product interaction. However, we need objective, measurable laboratory standards, which can be linked to subjective perceptions of comfort. Only in this way predictions can be made whether a particular design will be felt comfortable or not by the consumer.

On the other hand, fingertip is the most sensitive and important part of human body to obtain information by touching an objective. Finite element analyses have been performed to predict surface deformations of the fingertip [7], and geometry and a structural model of the fingertip pulp supported by experimental data have been developed to predict the force-displacement and force-contact area responses of the human fingertip during contact with a flat, rigid surface [8]. Moreover, the surface shape design method that took the tactile sensation into consideration has been proposed and the surface temperature has been used to present warmness of the surface [9]. However, no works can be found on trying to apply the finite element method to simulate the configuration change of the human fingertip when grasping an object and then to evaluate the touch feeling numerically.

This paper introduces the finite element analysis into the ergonomics to evaluate quantitatively perceptions of comfort. Two ergonomics design examples of aluminum beverage cans & bottles are described; one is the Stay-on-Tab (SOT) end with better finger access and another one is two-piece rib-shape embossed aluminum beverage bottles for hot vending. In the first example, the process of index finger pulling up the tab of SOT ends is simulated by the nonlinear finite element analyses, and the sensation of a pain in the fingertip is evaluated quantitatively by the maximum value of the contact normal stress. Three tab models with different shapes of the finger ring are analyzed and the finger access is compared.

This paper also ergonomically designs the rib-shape embossed body of the aluminum beverage bottle with temperate touch feeling in order to accommodate hot vended products. To evaluate the hot touch feeling, the finite element analyses of tactile sensation of heat are performed. The analysis of tactile sensation of heat includes the contact deformation analysis and heat transfer analysis between the finger and hot bottle body. The contact deformation analysis of fingers grasping the bottle is carried out first, and the amount of heat transmitted from the hot bottle to the flesh of fingers is then calculated. The tactile sensation of heat is presented by the amount of heat transmitted. The touch feeling of the cylindrical bottle and nine kinds of embossed bottles with different rib-shape designs are evaluated and compared.

ERGONOMICS DESIGNS OF TABS WITH BETTER FINERE ACCESS

Easy-open cans with SOT ends (Fig.1) have been developed more than twenty years before, and the functional problems such as the sealability and the end openability have been almost solved. The first step in opening the beverage can with the SOT end is to pull up the tab ring by index finger while pressing the tab nose by thumb, as illustrated in Fig. 2(a) [10]. The finger access is used to evaluate whether it is easy to insert fingertip into the gap between the ring and finger deboss of the can end, and whether it is painful when pulling up the finger ring. The easier the finger can be inserted and the ring can be pulled up, the better the finger access is evaluated. To improve the finger access, various methods have been developed. For example, deepening the finger deboss, curving up the ring, or applying scores to the panel under the tab so that the tab may float up a little when the can is filled with beverages and pressured. All of these methods are trying to enlarge the gap between the ring and the finger deboss to make fingertip go into the gap easily and consequently to improve the finger access. Since there are limitations of these methods, such as a clearance restriction between the tab and the top edge of the seaming wall, the geometrical shapes of the tab ring are investigated.

To evaluate the touch feeling of the pain (or comfort) in the finger when pulling up the tab ring, the finger access analysis model is developed as shown in Fig. 2(b). Assuming the deformations of tabs and finger models are symmetry to the central vertical plane, numerical analyses on 1/2 finite element model is performed by using the finite element code, MSC.MARC. All freedoms of the nodes on the circular edge of the rivet part of the tab are fixed. The edge nodes of the bone elements on the tip of the finger model are enforced to move 0.5 mm forward and then move upper forward. The maximum value of the contact normal stress of the finger model when pulling up tab is used to present the pain in the finger. The smaller the contact stress is, the less pain the finger experiences and the better the finger access of the tab is evaluated.

Figure 3 shows the schematic diagram of the distal part of finger [11]. The fingertip is simplified as a elastic model with two kinds of mechanical properties, bone and soft tissue, as shown in Fig.4. The mechanical properties of bone and soft tissue of index fingertip model are assumed as: Young's modulus E = 17GPa, 5 MPa, Poisson's ratio ν = 0.3, 0.45,

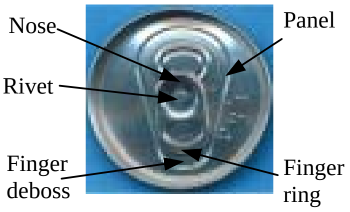


FIGURE 1. A Stay-On-Tab end.

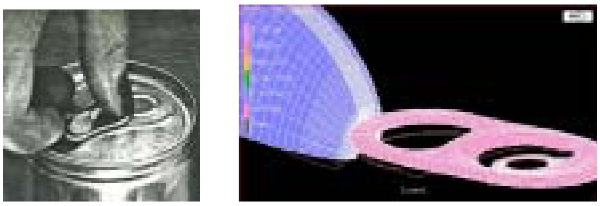

(a) (b)

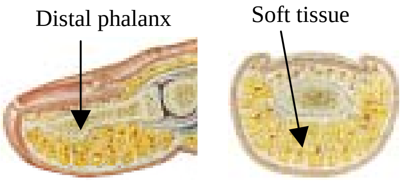
FIGURE 2. Finger access analysis model.

respectively. The model is descritized into eight-node solid elements. Since bone hardly deforms during pulling up the tab, only one layer of elements is defined as bone in order to save the computational cost. The material model used for the aluminum tab is assumed as an elasto-plastic von Mises material with isotropic hardening. Young's modulus E = 70 GPa, Poisson's ratio ν = 0.33 and yielding stress σ = 260 MPa are assumed. In order to investigate the effect of the geometric shape of the finger ring of the tab, three kinds of shape designs, i.e., the convex ring (model N1), the flat ring (model N2) and the concave ring (model N3), are modeled as shown in Fig.5. The tab model N3 is designed to match the shape of finger pulp. The length of the symmetry central lines and the symmetry central cross-sections of three tab models are the same. The tab model is descritized into four-node shell elements with 0.33 mm thickness.

Figure 6 shows the deformation of the finger surface and the contact normal stress distribution of finger model when the tab model N1 is pulled up 2.5 mm. It is obvious that the stress concentration occurred at the part in contact with the central part of the convex ring. When the displacement of the ring center (H_1) becomes 2.5 mm, finger can be inserted more and the tab can be re-held for an easy open. The difficulty is evaluated by the can openability rather than the finger access when H_1 is larger than 2.5 mm, so the simulation results before H_1 becomes 2.5 mm are observed. The maximum value of the contact normal stress, the contact areas, and the maximum value of the equivalent elastic strain of the finger are compared in Fig.7 for three tab models when H_1 = 2.5mm. In the case of the tab with a concave ring, the contact area between the finger and ring is the largest and the maximum value of the contact normal stress and equivalent strain are the smallest. It is considered that if a larger area shares the load that required for pulling up the tab, the contact normal stress and equivalent strain may become lower; hence, the pain in the finger may decrease more. Therefore, it is concluded that the finger access of the tab that may have a larger contact area with finger is better. The finger access of the tab with a concave ring is better than that of the tab with a flat ring. The finger access of the tab with a convex ring is the worst.

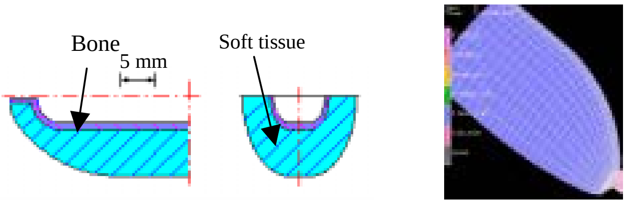
ERGONOMICS DESIGNS OF BOTTLES FOR HOT VENDING

In winter, hot vending of beverages is expected in Japan. However, when aluminum bottles are warmed up to about 60°C in vending machines, they are too hot to be held by hand due to the high thermal conductivity of aluminum. Therefore, in developing the aluminum beverage bottles for hot vending, it is also necessary to take the tactile sensation of heat into consideration. In order to make aluminum bottles adaptable to hot vending market, two ways are developed. As shown in Fig.8, one way is to wrap bottle bodies with a printed PET label to reduce the thermal conductivity, and another one is to add ribs to



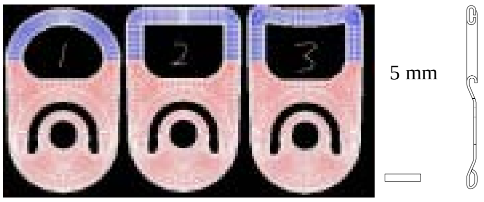
(a) Vertical cross-section (b) Transverse cross-section

FIGURE 3. The schematic diagram of finger [11].



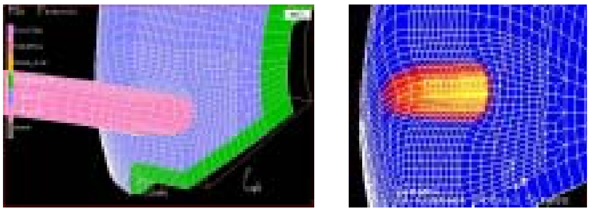
(a) Vertical cross-section (b) Transverse cross-section (c) Finite element model

FIGURE 4. Model of distal part of index finger.



(a) Finite element model (b) Cross-section

FIGURE 5. Pull-tab models.



(a) Finger and tab. (b) Contact stress distribution

FIGURE 6. Simulation results of tab model 1.

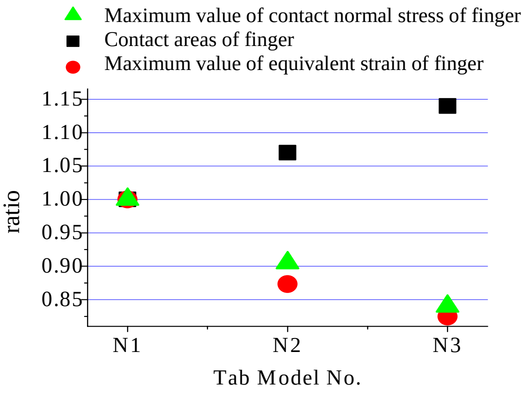


FIGURE 7. Analysis results.

the bottle wall by an embossing process. The ribs can reduce the amount of heat transmitted to the finger and the air gap between the embossed body and the PET label can weaken further the heat transfer. In order to evaluate numerically the hot touch feeling of the finger when holding the hot beverage bottle, finite element analyses of the tactile sensation of heat are performed. Numerical analyses of the tactile sensation of heat include contact deformation analyses and heat transfer analyses between the finger and bottle body, as shown in Fig.9. In the contact analyses, the fingertip is contacted with the cylindrical body or mountain of the rib-shape embossed body, and a distributed load *p* toward the bottle is applied to the upper surface of the finger model. The deformed configuration of the finger obtained in the contact analysis is then used in the heat transfer analyses. Figure 10 shows the cross sections of the fingertip and rib-shape embossed bottle body. The embossed body of sixteen ribs is considered in this paper, i.e., A_1 = 22.5^o. The radii used for the analysis of the tactile sensation of heat are R_a = 32 mm, R_b = 33.15 mm. The material constants of the finger are assumed as: Young's modulus E = 100 MPa, Poisson's ratio ν = 0.45, thermal conductivity $\lambda = 0.5\ \mathrm{W/(m \cdot K)}$, specific heat $c = 3400\ \mathrm{J/(kg \cdot K)}$. The finger model is descritized into four-node quadrilateral elements, and the embossed bottle is assumed as a rigid body of 60^{o}C. The initial temperature of the finger is set as 35^{o}C and the temperature of the nodes on the upper surface of the finger model are fixed as 37^{o}C. The contact heat transfer coefficient between the finger and the bottle body is assumed as $46\ \mathrm{W/(m^2 \cdot K)}$. The finite element code, MSC.MARC, is used again to simulate the configuration change of the finger and to calculate the amount of heat transmitted from the hot bottle to the flesh of the finger when grasping the bottle body.

In order to gain a deeper understanding of the influence of rib dimensions A_2, A_3 and A_4 to the tactile sensation of heat, model M0 with no embossing process and nine embossed body models listed in Table 1 are analyzed. The value of A_4 was calculated using Eq.(1),

$$A_4 = \pi - \beta + A_2/2 \qquad (1)$$

where, $\beta = \arcsin(R_a \sin\alpha / \sqrt{R_a{}^2 + R_b{}^2 - 2R_aR_b\cos\alpha})$ and $\alpha = (A_1 - A_2 - 2A_3)/2$.

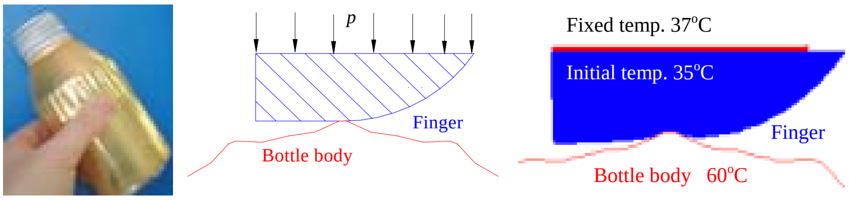
It is clear that with the angle A_2 or A_3 increasing, A_4 increases and the slope of the mountain and valley of the rib becomes steeper.

Since the force required for holding the bottle body is dependent on the weight of the bottle filled with beverage as well as the friction coefficient between the finger and printed bottle body, contact simulations are performed when five levels of the load, p = 1.5, 2.5, 3.5, 4.5 and 5.5MPa, are applied to the finger model, respectively. The amount of heat transmitted from the bottle in a unit time is calculated using Eq.(2),

$$Q = c \cdot \sum_{i=1}^{n} S_i \cdot (\overline{T}_i - \overline{T}_{i0}), \qquad (2)$$

where, n is the number of elements, S_i is the area of the element i, $\overline{T}_{i0}$ and $\overline{T}_i$ are the initial mean temperature and the mean temperature at a unit time of element i, respectively. The ratio of the amount of heat transmitted from the hot bottle is calculated as

FIGURE 8. Beverage bottles for hot vending.



(a) Finger & bottle (b) Contact analysis model (c) Heat transfer analysis model

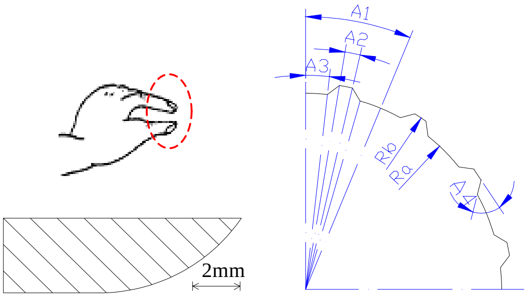
FIGURE 9. Analysis model of tactile sensation of heat.

$\delta = Q / Q_0$, where Q_0 is the amount of heat transmitted from the bottle model M7 when p = 2.5 MPa is applied to the finger model. The heat transfer analysis results at 0.03 second are compared in Fig.11 for all models. It is obvious that all embossed bottle body models transfer less heat to the finger than the un-embossed cylindrical body model M0 does, when the same load p is applied to the finger. For example, the amount of heat transmitted from model M7 is 26.7% smaller than that of model M0 when load p = 2.5 MPa is applied. The range of the ratio in Fig.11 tells us that the influence of the level of load p decreases with the value of A_2, A_3, A_4 increasing.

Figure 12 shows the temperature distributions of the finger models at 0.03 second when grasping hot bottle models. It is found that the temperature of the finger grasping embossed bottle body is lower than that of un-embossed bottle body. We observed that with the load p increasing, the configuration of the flesh of the finger grasping embossed bodies changes in three steps: (1) covering the top of the mountain of the rib as shown in Fig. 12(a); (2) climbing downward along the side wall of the rib as shown in Fig. 12(b); and (3) arriving the valley of the rib as shown in Fig.12(c). In the first step, with A_2 decreasing or A_4 increasing, the contact area between the finger and bottle body decreases. In the second step, A_4 influences the contact area more. As well known, the amount of heat transmitted increases with the contact area increasing. Hence, if the load p is not large enough to enable the flesh of the finger cover down from the top of the mountain, the amount of heat Q transmitted to the finger decreases with A_2 decreasing. If the load p is large enough to enable the flesh of the finger to climb downward the mountain, Q decreases with A_4 increasing. This is why the amount of heat Q of model M3 is smaller than that of model M6 when p = 2.5 MPa, and larger than that of model M6 when p increases to 4.5 MPa. In the third step, the contact area increases rapidly. This is the reason why Q of model M3 increases much when load p becomes 5.5 MPa.

TABLE 1. Dimensions of embossed body models.

Model	**A_2 (Degree)**	**A_3 (Degree)**	**A_4 (Degree)**
M0	--	--	--
M1	1.5	1.5	17.89
M2	1.5	3.5	20.35
M3	1.5	5.5	25.26
M4	3.5	1.5	19.92
M5	3.5	3.5	23.36
M6	3.5	5.5	30.57
M7	5.5	1.5	22.35
M8	5.5	3.5	27.26
M9	5.5	5.5	38.23



(a) Finger model. (b) Rib-shape embossed bottle body.

FIGURE 10. Cross-sections.

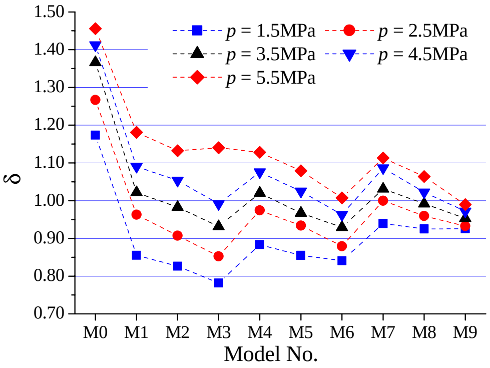
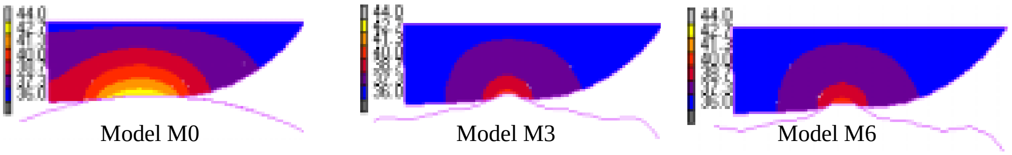


FIGURE 11. Heat transfer analysis results.

From the comparison of the amount of heat transmitted from the hot bottle body, it is clear that the sharper the mountain of the rib is, the smaller the contact area becomes and then the less the heat is transmitted. It is concluded that the rib-shape of the embossed bottle of relatively small value of A_2 as well as large value of A_4 has better touch feeling.

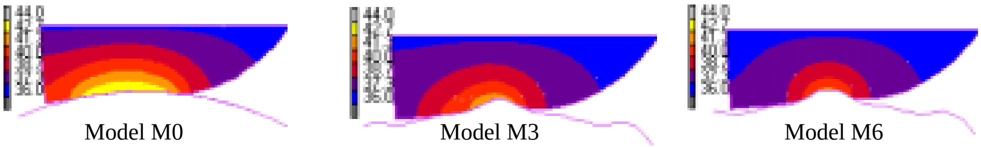
CONCLUSIONS

This paper introduced the finite element analyses into the ergonomics designs to evaluate the human feelings numerically and objectively. Two design examples in developing the aluminum beverage cans & bottles are presented. In the first design example, simulation of finger pulling up the tab was performed and the pain in the finger is presented using the maximum value of the contact stress of the fingertip model. The finger access comparison of three kinds of ring shape designs showed that the finger access of the tab that may have a larger contact area with finger is better. In the second design examples, the analyses of tactile sensation of heat were performed and the amount of heat



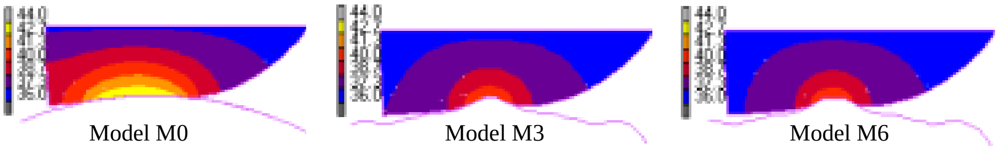
Model M0 Model M3 Model M6

(a) p = 2.5 MPa.



Model M0 Model M3 Model M6

(b) p = 4.5 MPa.



Model M0 Model M3 Model M6

(c) p = 5.5 MPa.

FIGURE 12. Temperature distribution of the finger model.

transmitted from hot bottles to fingers was used to present the hot touch feeling. Comparison of beverage bottles for hot vending showed that the touch feeling of rib-shape embossed bottles is better than that of regular bottles, and that the rib shape also influenced the hot touch feeling.

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