

Evaluation of drinking ease relative to the opening diameter and beverage type of aluminum beverage bottles

メタデータ	言語: English 出版者: 公開日: 2017-10-03 キーワード (Ja): キーワード (En): 作成者: Chihara, Takanori, Yamazaki, Koetsu, Itoh, Ryoichi, Han, Jing メールアドレス: 所属:
URL	http://hdl.handle.net/2297/19915

1 Evaluation of Drinking Ease Relative to the Opening Diameter and
2 Beverage Type of Aluminum Beverage Bottles

3 Running title: Drinking Ease of Aluminum Beverage Bottles

4
5 Takanori Chihara^{a,*}, Koetsu Yamazaki^a, Ryoichi Itoh^b, Jing Han^b

6
7 ^a*Graduate School of Natural Science and Technology, Kanazawa University, Kakuma-mach, Kanazawa, Ishikawa,*
8 *920-1192, Japan*

9 ^b*Universal Can Corporation, 1500, Saganuma, Oyama, Sunto, Shizuoka, 410-1392, Japan*

10 ^{*}Corresponding author (E-mail: chihara4@stu.kanazawa-u.ac.jp)

11
12 **Abstract**

13 This paper investigates the effects of different bottle opening sizes (28, 33, and 38 mm in diameter) and beverage types
14 (e.g. green tea, carbonated beverages) on the drinking satisfaction of consumers, in order to enhance their comfort levels
15 when drinking from aluminum beverage bottles. A survey of 120 Japanese subjects was conducted, and the 33 mm
16 opening size emerged as the most preferred, irrespective of beverage type. The factor analysis results of the
17 questionnaire show that drinking satisfaction is primarily affected by two common factors: the volume of flow from the
18 bottle to the mouth and the adjustability of the flow. The results of the three-dimensional fluid-dynamics analysis
19 indicate that differences in beverage type could influence what consumers regard as an appropriate flow.

20
21 **Key words:** Ergonomics, Drinking ease, Aluminum beverage bottle, Computational fluid dynamics

22
23 **1. Introduction**

24 In addition to rudimentary factors like functionality, performance and price, there are other vital areas like usability,
25 novelty in design, and conformity with fashion, which affect customers' decisions while purchasing products.
26 Manufacturers are, therefore, expected to adopt consumers' sensibilities and preferences in their designs, rather than
27 bank on performance alone for acceptance of their products in the marketplace. From the viewpoint of universal design,
28 it is important to design products that can be used comfortably across all age and gender groups. In order to obtain data
29 for determining consumers' preferences, surveys of trained panelists or consumers are usually carried out, using trial
30 products. The Semantic Differential (SD) method (Iwashita, 1983) and the Factor Analysis (FA) method (Richard, 1983;

31 Shiba, 1979) are typical techniques used in such questionnaires. In addition, this study employs the Kansei Engineering
32 method, initially proposed by Japanese researchers as a system of rendering thoughts and sensations into product
33 parameters, and now used internationally by designers as a design methodology (Nagamachi et al., 1974; Nagamachi,
34 1995, 2000). In the product designing stage, numerical simulation serves as an important cost and time saving tool by
35 averting the need to make a lot of trial products; numerical simulation is used in this study to estimate whether a
36 particular design will be loved by consumers or not. Structure optimization techniques based on the Finite Element
37 Analysis (FEA) have been applied to develop 2-piece aluminum beverage cans and bottles in order to get better
38 performance under various loading conditions; for instance, making the lid light-weight can counter subject to the
39 constraints of the buckling strength and maximize the strength of the bottle bottom against the axial load and internal
40 pressure (Yamazaki et al., 2007; Han et al., 2005). Improved shelf life (the length of time that packaged food can be
41 stored), visual appeal, and price are among the anticipated benefits of these beverage containers. In addition, universal
42 designs based on ergonomics have been applied while developing beverage containers and are expected to enhance
43 consumers' convenience (Han et al., 2004; Han et al., 2006; Nishiyama, 2001; Ueno, 2003).

44 Aluminum beverage bottles with screw tops have been launched in the Japanese market in recent years to meet the
45 modern-day drinking habits of consumers. These can be repeatedly resealed, and are designed to recycle many times
46 better than the resealable PET bottles. In addition, these are used by all consumers, irrespective of age and gender. Thus,
47 the universally used aluminum beverage bottles form the focus of this research, which is based on ergonomics and the
48 Kansei engineering evaluation method that considers physiological and psychological effects on human respondents.
49 Consumers in general have several ways of drinking: directly from the bottle opening, with a straw, or from a glass.
50 Because aluminum beverage bottles can be resealed, consumers often take these with them outdoors, and drink directly
51 from the opening. It is, therefore, important for makers of aluminum beverage bottles to consider minutely the
52 satisfaction levels of consumers drinking directly from the bottle opening. Although aluminum beverage bottles with 28
53 mm and 38 mm opening diameters are familiar to Japanese consumers, a majority of them feels that the 28 mm opening
54 is too small and considers the 38 mm opening too large. Researchers have, in the past, conducted studies concerning the
55 "openability" of the closures of food and beverage containers. These studies were based on mechanical evaluation,
56 which considered force, torque and friction (Lewis et al., 2007; Yoxall and Janson; 2007; Carus et al., 2006). The
57 subject of drinking ease (in relation to the attributes of beverage containers) has, however, not been studied so far; this
58 is because a study of drinking ease is dominated by the sensory evaluation of consumers, which makes it difficult to
59 adopt traditional mechanical evaluation techniques. Therefore, we need to develop a method to evaluate human feelings
60 when drinking directly from the bottle opening and then identify the opening size that is most suitable for consumers'
61 drinking satisfaction.

62 In addition, physical factors of drinking satisfaction should be extracted so as to evaluate the drinking satisfaction
63 quantitatively, and the flow in the bottles or the flow rate at the bottle outlet may be related to the drinking satisfaction.
64 Consequently, subjective evaluation (i.e. drinking test and the FA method) and numerical analysis (i.e. fluid-dynamics
65 analysis) will support each other, and they will evaluate the effects of the bottle opening size on drinking satisfaction. At
66 first, this paper analyzes data from a survey of 120 young Japanese subjects, based on a drinking test that is conducted
67 using three kinds of experimental bottles with opening diameters of 28 mm, 33 mm and 38 mm. In addition, green tea
68 and a carbonated beverage (coke) were selected as test beverages so as to investigate the influence of the beverage type.
69 Questionnaires based on the Kansei Engineering method were circulated, and the drinking test was performed. The
70 results of the test are statistically analyzed to yield data that will determine, in the course of this paper, the consumers'
71 preference among the three opening sizes. The FA technique is used to identify the factors that influence consumers'
72 drinking feelings and investigate the extent of such influences. Further, a fluid-dynamics analysis model is developed to
73 simulate the flow of bottled liquid during a drinking action. The factors influencing the drinking feeling are evaluated
74 numerically, based on the results of the survey and the experimental observations of consumers' drinking actions.

75

76 **2. Survey on the Drinking Test**

77 **2.1 The Drinking Test Method**

78 The survey had 120 young Japanese volunteers as respondents: 60 males and 60 females. All of them are college or
79 university students, and are between 20–26 years of age. Although this study had intended to cover all age groups, the
80 respondents were exclusively young students because their cooperation was obtained without any difficulty. As shown
81 in Fig.1, all subjects sat while drinking and then filled out questionnaires that aimed to define the extent of drinking
82 satisfaction.

83 Fig.2 shows samples of three kinds of experimental bottles with opening diameters, 28 mm, 33 mm and 38 mm.
84 The 28 mm and 38 mm opening diameters are familiar to Japanese consumers, but a majority of them feels that the 28
85 mm opening is too small and the 38 mm opening is too large. Therefore, we predict that the 33 mm opening diameter,
86 which is intermediate in size between 28 mm and 38 mm, will possibly improve drinking satisfaction, and it is selected
87 to be used as the experimental bottle. These bottles have a capacity of 300 ml and are filled with 200 ml of liquid, which
88 allows for an intermediate level of the capacity. All subjects were asked to have one mouthful of drinks from each kind
89 of bottle. The respondents were gathered into six groups numbering twenty each; six different drinking orders were set
90 for the three bottle opening sizes, in order to avoid any possible influence of the drinking order. To investigate the
91 influence of the beverage type, green tea and the carbonated beverage were chosen as test beverages.

92 The questionnaires, which are based on the Kansei engineering method, are designed to investigate the factors that

93 influence consumers' feelings while drinking. In general, consumers' feelings may be related to the container (the
94 opening size, shape and material), the beverage type (the temperature and taste), personal factors (the age, gender and
95 way of drinking) and the environment (the place and time). In the engineering context, drinking satisfaction may be
96 affected by the volume of flow into the mouth, and by issues like adjustability and stability while drinking. Eleven
97 evaluation items were selected based on the Kansei model to identify and study the drinking satisfaction. Fig. 3 shows
98 the questionnaire for the 28 mm bottle opening. The evaluation items were the same for all kinds of beverages and
99 bottles. The SD method was used, and five levels were set to calculate responses.

100 **2.2 Statistical Results of the Questionnaire**

101 Figs.4 and 5 show questionnaire results based on the drinking test using bottles filled with green tea and the
102 carbonated beverage, respectively. The mean values and standard deviations are calculated for the eleven evaluation
103 items. It is found that the mean values for the 33mm opening are high in general, no matter what the beverage type. The
104 38 mm bottle opening shows the highest mean values for Item 1 (Liquid can easily flow out from the bottle), Item 3
105 (The flow volume through the opening is large) and Item 5 (The flow into the mouth is fast), while the 28 mm opening
106 shows the highest mean value for Item 8 (Liquid hardly spills from corners of the mouth). It is also apparent that the
107 standard deviations of the 33 mm bottle opening are generally lower than that of the other two opening sizes,
108 irrespective of the beverage type.

109 Since the 33 mm opening shows the highest mean values and the lowest standard deviations for virtually all
110 evaluation items, the 33 mm opening is clearly highly evaluated by all respondents, irrespective of the beverage type. In
111 contrast, the 28 mm and 38 mm bottle openings show relatively high standard deviations, which indicate that subjects
112 have mixed feelings while drinking from these. The 33 mm opening shows a smaller value for Item 3 (The flow volume
113 through the opening is large) but a higher value for Item 2 (The flow volume through the opening is appropriate) when
114 compared with the 38 mm opening. We may, therefore, estimate that there is an appropriate flow of beverages for
115 subjects to feel comfortable when drinking from the bottles.

116 All subjects were asked to rank the three kinds of bottles in the order of drinking ease so as to determine their
117 preference of opening size. The ranking results for green tea and the carbonated beverage, as submitted by all subjects,
118 are shown in Table 1 (a) and (b), respectively. With 3 points given to the first rank, 2 points to the second and 1 to the
119 third, the total ranking scores of the three kinds of bottles are calculated as shown in the last column of Table 1. It is
120 found that the 33 mm opening scores the highest among the three opening diameters, irrespective of beverage type. The
121 ranking scores are plotted in Fig.6, which facilitates the investigation of the influence of the beverage type and the
122 gender of the drinker on the drinking satisfaction obtained. It is established that the first rank is held by the 33 mm
123 opening in the drinking tests, of both green tea and the carbonated beverage, across both gender groups. Comparing the

124 ranking results for the 28 mm and 38 mm openings, it is observed that consumers prefer to drink green tea from a
125 relatively large opening, and carbonated beverages from a relatively small one. However, the differences in scores are
126 small in comparison with the universal preference for the 33 mm opening.

127 To investigate the influence of the subjects' mouth sizes on drinking ease, the width (w) and height (h) of the
128 mouth were measured for all subjects while keeping the mouth naturally closed, as illustrated in Fig.7 (a) (National
129 institute of bioscience and human-technology, 1996). The number of subjects, classified by mouth width into five
130 ranges—(1) 35 mm–40 mm, (2) 41mm–45mm, (3) 46 mm–50 mm, (4) 51 mm–55 mm, and (5) 56 mm–60 mm, and into
131 four ranges of mouth height—(1) 9 mm–15 mm, (2) 16 mm–20 mm, (3) 21 mm–25 mm, and (4) 26 mm–30 mm, are
132 shown in Fig.s 7 (b) and (c). The drinking ease is assigned as shown in Fig.s 8 (a) and (b). Comparing the drinking ease
133 figures attributed to the 28 mm and 38 mm openings in Fig.8 (a), we observe that subjects with large mouth sizes tend
134 to prefer the 38 mm opening to the 28 mm opening. The superceding result, however, is that the 33 mm opening stays at
135 top preference in every category of mouth size. We may, therefore, conclude that the 33 mm opening is best suited for
136 Japanese adult consumers' ease of drinking as its preference is dominant everywhere in our statistical analysis,
137 prevailing in all segments by gender, beverage type and mouth size.

138 **2.3 Results of the Factor Analysis (FA)**

139 The FA is performed in order to gain insight into the data obtained from the responses to the questionnaires. The
140 FA results are shown in Table 2, Table 3 and Fig.9. We can understand the characteristics of identified factors and of the
141 three opening diameters from Fig.s 9 (a) and (b), respectively. Two common factors have been identified. The
142 contribution rate of the 1st factor (54.7%) is greater than that of the 2nd factor (45.3%), which indicates that the 1st
143 factor affects drinking ease more than the 2nd. The communality of the fluctuation rate of the two factors is 95.9%,
144 which implies that the fluctuation in the drinking test results can almost entirely be explained by these two factors.

145 The horizontal axes in Figs.9 (a) and (b) indicate the 1st factor, and the vertical axes represent the 2nd factor. Item
146 1 (Liquid can easily flow out from the bottle), Item 3 (The flow volume through the opening is large) and Item 5 (The
147 flow into the mouth is fast) ascribe large weight to the 1st factor; Item 8 (Liquid hardly spills from corners of the
148 mouth), on the other hand, assigns a small (negative) weight to the 1st factor. Further, Item 2 (The flow volume through
149 the opening is appropriate) and Item 10 (The bottle opening fits with the mouth) ascribe large loads to the 2nd factor.
150 Therefore, the flow amount may be considered to be the 1st factor, and flow adjustability, as the 2nd factor. Good
151 adjustability of flow would imply that the surge of beverage from the bottle opening can be easily and appropriately
152 adjusted, in line with consumer expectations.

153 In Fig.9 (b), the 38 mm opening shows the highest scores for the 1st factor, followed by the 33 mm opening, and
154 the 28 mm opening, independent of the beverage type. In other words, subjects recognize that the flow volume from the

155 38 mm opening is large, followed by the 33 mm and 28 mm openings. The factor score, in the case of the 2nd factor, is
156 highest for the 33 mm bottle opening for any beverage type, which indicates that subjects recognize that the flow
157 adjustability of the 33 mm opening is the best, irrespective of the beverage being consumed. In addition, the difference
158 in the 2nd factor scores between green tea and the carbonated beverages for the 33 mm opening is smaller than that for
159 the 28 mm and 38 mm openings. Therefore, the adjustability between beverage types of the 33 mm opening may be
160 considered more robust than that of the 28 mm and 38 mm openings. Between the 28 mm and 38 mm openings, the 2nd
161 factor score in the case of the carbonated beverage is higher for the former, while in the case of green tea the 2nd factor
162 score is higher for the latter. Thus, the subjects felt that it is easier to adjust when one drinks the carbonated beverage
163 from a bottle with a relatively small opening. This may be explained by the fact that carbonated beverage has a
164 tendency of foaming; thus, the 28 mm opening, which permits a smaller flow amount, makes it easier to adjust than the
165 38 mm opening. Therefore, preferences of the opening diameter's dimensions may change according to the taste and
166 features of beverage types. However, the range of possible preferences is narrow, and centered around 33 mm.

167

168 3. Numerical Simulations

169 3.1 The Flow-Dynamics Analysis Model

170 The survey results based on the drinking test show that the beverage flow exerts a great influence on drinking ease,
171 which makes it necessary to develop a three-dimensional flow-dynamics analysis model to estimate the flow-out of
172 beverage from the bottle and to evaluate the drinking ease numerically, instead of relying on experimental observation.

173 The analysis model is developed as shown in Fig.10, and the properties adopted for consideration are tabulated in
174 Table 4. To simulate the drinking action, the bottle model is rotated from its initial upright position to the inclined
175 drinking position at a constant velocity, and then stopped; the entire action is completed in 2.0 seconds. The inclination
176 angle (θ) of the bottle, shown in Fig.10 (b), is defined as the acute angle between the bottle's central axis and the
177 horizontal plane.

178 The velocity boundary condition is applied to the wall and bottom of the bottle (Γ_1, Γ_2), and no relative velocity
179 between the fluid and the bottle is considered. The distributed load boundary condition is applied to the opening of the
180 bottle, defined as the flow outlet (Γ_3), and the pressure on the boundary is equal to zero. The bottle model is filled with
181 200 ml of water, which is assumed to flow out of the bottle without any external resistance. The water and the air in the
182 bottle are assumed to be incompressible fluids. In addition, the flow in the bottle is assumed as turbulent flow, and the
183 zero-equation type turbulence model with mixing length is applied to the eddy viscosity model. The VOF method is
184 used in order to represent the interface between the water and the air. In addition, the water is assumed to have no
185 surface tension. When the water flows out from the bottle outlet, air that has the same volume as the outflow water

186 flows into the bottle. The computational fluid dynamics analysis code, FIDAP 8.7 (Fluent Incorporated), is used to
187 estimate the flow of fluid during the drinking action. The finite element method is used, and the Galerkin form of the
188 method of weighted residuals and implicit backward Euler are used for spatial and temporal schemes, respectively.
189 Moreover, hexahedral solid elements are used for all models, and the number of nodes and elements are about 55,000
190 and 60,000, respectively.

191 The drinking actions of five subjects were recorded using a video recorder in order to measure the final inclination
192 angle (θ_e) of the bottle while subjects performed the drinking action. The average values of the final inclination angles
193 are shown in Table 5. The inclination angles for green tea and the carbonated beverage obtained experimentally have
194 been set on Models named G1, G2, and G3 for green tea and C1, C2, and C3 for the carbonated beverage (Table 6). In
195 addition, $\theta_e = -2.0^\circ$, the same final inclination angle as that of Model G2 (33 mm opening bottle), is set for Model G4
196 (28 mm opening) and G5 (38 mm opening). All models are started from $\theta = -90^\circ$ and rotated to their final inclination
197 angles.

198 **3.2 Flow-Dynamics Analysis Results**

199 The numerical simulation results of the 33 mm opening bottle (Model G2) are shown in Fig.11. It is observed that
200 the water flows out from this bottle without crashing with the tapered part of the bottle and undulating deeply. Similar
201 behavior of flow is noted in the simulations of the other models.

202 Fig.12 illustrates the history plots of the flow rates for five models; Table 6 shows the average flow rates of all
203 models, where ‘start time’ is defined as the beginning of the outflow, and ‘end time’ is defined as the time at the local
204 minimum point after the 1st peak. In addition, the average flow rate is defined as the average between the start time and
205 the end time. From Fig.12, it can be observed that two peaks appear in the plot for all models, because the second peak
206 is formed by a wave that is reflected by the bottom of the bottle. Moreover, it is observed that the starting time and the
207 duration of the two peaks are almost identical among the five models in spite of the differences in opening size and the
208 final inclination angle. The amplitude of the first peak is different for each of the five models.

209 If the final inclination angle is given as $\theta_e = -2.0^\circ$, the numerical analysis results of Model G2, G4, and G5 show
210 that the average flow rate of the 33 mm bottle is smaller than that of the 38 mm bottle, but greater than that of the 28
211 mm bottle. The range of differences is about 50%. However, if the final inclination angles measured experimentally are
212 assigned to the models (G1, G2, and G3), the range of differences in the average flow rate becomes as narrow as about
213 10%. Moreover, comparing the average flow rate of green tea models (G1, G2, and G3) and that of carbonated beverage
214 models (C1, C2, and C3), it is clear that the average flow rate of the carbonated beverage models is lower for all
215 opening diameters, even though the same material properties of fluid are assumed.

216 **3.3 Discussions**

217 Based on the results from the fluid dynamics analysis, it is observed that the flow-out behavior is almost the same
218 in the simulations of all models. Therefore, it is probable that the flow-out behavior of bottled liquid does not affect
219 drinking ease in case of usual drinking actions. On the other hand, the amplitude of the first peak is different for each
220 model. In addition, the flow amount may be considered to be the first factor resulting from the FA of the questionnaire
221 data. Hence, the average flow rate is required, not the maximal value, because multiplying the average flow rate by the
222 duration time gives the flow amount from the bottle opening. Therefore, the average flow rate defined above may be
223 examined to yield a relationship between drinking ease and one of the engineering variables. This agrees with the FA
224 results in that the flow has an effect on drinking ease.

225 The range of differences in the average flow rate of experimental angle conditions is narrower than that of constant
226 angle conditions. If the flow of liquid from the 33 mm bottle is regarded as the appropriate flow, consumers probably
227 adjust the inclination angle of other bottles to achieve the requisite flow for drinking ease. This agrees with the results
228 from the drinking test and the questionnaires that there is an appropriate flow of beverages for subjects feeling
229 comfortable. Moreover, the average flow rate of carbonated beverage models is lower than that of green tea models for
230 all opening diameter. The explanation for this is the propensity for foaming that is inherent in carbonated beverage,
231 which causes its appropriate flow for drinking ease to be lower than that of green tea. Therefore, differences in beverage
232 type could bring about changes in what consumers may regard as appropriate flow.

233 From the statistical analysis of the questionnaires and fluid-dynamics analysis, this paper has established that there
234 is indeed an appropriate level of flow of beverage that allows subjects to feel comfortable when drinking from an
235 aluminum bottle. Especially the average flow rate is an important indicator that allows drinking satisfaction to be
236 evaluated quantitatively. In addition, we have seen that the flow-dynamic analysis model can explain the observations
237 noted in the drinking test and questionnaires, the flow-dynamic analysis model may be utilized to further develop
238 containers that would ensure consumers' ease of drinking. Moreover, it may be concluded that the 33 mm opening is
239 best suited for Japan's young adult consumers across all beverage types, gender groups and mouth size segments.

240

241 4. Conclusions

242 The results of the FA performed with the SD method show the existence of two factors that are primarily
243 responsible for the quality of the drinking feeling; the first factor corresponds to the flow amount and the second factor
244 relates to the flow adjustability. In addition, the results of the fluid-dynamics analysis show that the average flow rate of
245 the bottled liquid may be used to represent the state of drinking ease, and that consumers usually try to realize the ideal
246 flow rate condition by adjusting the inclination angle of the bottle. The results obtained from the fluid-dynamics
247 analysis agree with the FA in that the flow amount and the flow adjustability affect drinking ease. Therefore, it is

248 important that designers of beverage bottles consider, accommodate and utilize these two factors, in order to secure the
249 progress toward greater drinking satisfaction.

250 In order to further enhance the comfort levels of consumers when drinking directly from the bottle opening, the
251 flow-dynamics analysis model developed in this paper may be used to investigate the effects of the bottle shape,
252 opening shape, material and so on. To achieve a developed analysis model for more elaborate evaluation of drinking
253 satisfaction, the number of subjects should be increased. As the next step of this study, drinking actions will be
254 measured by a large number of subjects that cover broad ranges of age, body size, and body shape. In addition, we will
255 also quantify individual differences of drinking actions and the uncertainty of human's behavior. Then an analysis
256 model may be developed to incorporate further details into the analysis, including human mouth sizes, mouth shape,
257 and the role of the hand, in order to investigate the influence of consumers' mouth size, mouth shape, and drinking
258 action on drinking ease. Moreover, the average flow rate will be used as the indicator of drinking satisfaction; that is,
259 drinking satisfaction may be represented quantitatively. Therefore, in future studies, we may specify the rigorous
260 dimension of the opening diameter for drinking ease due to quantitative evaluations of the flow rate.

261

262 References

263 Iwashita, T. (1983). *Measurement of image by SD method* (pp.1-129). Kawashima Publishing, Tokyo.

264

265 Richard L. Gorsuch. (1983). *Factor Analysis* (2nd ed., pp.1-347). Lawrence Erlbaum, Philadelphia

266

267 Shiba, S. (1979). *Factor Analysis* (pp.1-194). University of Tokyo Press, Tokyo.

268

269 Nagamachi, M., Senuma, I., & Iwashige, R. (1974). A study of emotion-technology. *The Japanese Journal of*
270 *Ergonomics*. 10(4), 121-130.

271

272 Nagamachi, M. (1995). Kansei Engineering: A New Ergonomic Consumer-Oriented Technology for Product
273 Development. *International Journal of Industrial Ergonomics*. 15(1), 3-11.

274

275 Nagamachi, M. (2000). Perspectives of Kansei Engineering. *Technical Report of IEICE OME*. 100(252), 167-173.

276

277 Yamazaki, K., Itoh, R., Watanabe, M., Han, J., & Nishiyama, S. (2007). Applications of structural optimization
278 techniques in light weighting of aluminum beverage can ends. *Journal of Food Engineering*. 81(2), 341-346.

279

280 Han, J., Itoh, R., Nishiyama, S., & Yamazaki, K. (2005). Application of Structure Optimization Technique to Aluminum
281 Beverage Bottle Design. *Structural and Multi-disciplinary Optimization*. 29(4), 304-311.

282

283 Han, J., Yamazaki, K. & Nishiyama, S. (2004). Optimization of the Crushing Characteristics of Triangulated Aluminum
284 Beverage Cans. *Structural and Multidisciplinary Optimization*. 28(1), 47-54.

285

286 Han, J., Yamazaki, K., Itoh R. & Nishiyama, S. (2006). Multi-Objective Optimization of a Two-Piece Aluminum
287 Beverage Bottle Considering Tactile Sensation of Heat and Embossing Formability. *Structural and Multidisciplinary*
288 *Optimization*. 32(2), 141-151.

289

290 Nishiyama, S. (2001). Development and Future Subjects of Aluminum Beverage Cans. *Packpia*. 45(2), 10-15.

291

292 Ueno, H. (2003). Drinks Cans with Customer Convenience. *In Proceedings of the Canmaker Summit [CD-ROM]*.
293 Singapore.

294

295 R. Lewis, C. Menardi, A. Yoxall & J. Langley, (2007). Finger friction: Grip and opening packaging. *Wear*. 263(2007),
296 1124-1132.

297

298 A. Yoxall & R. Janson, (2007). Fact or friction: a model for understanding the openability of wide mouth closures.
299 *Packaging Technology and Science*. 21(3), 137-147.

300

301 D. A. Carus, C. Grant, R.Wattie & M. S. Pridham, (2006). Development and validation of a technique to measure and
302 compare the opening characteristics of tamper-evident bottle closures. *Packaging Technology and Science*. 19(2),
303 105-118.

304

305 National Institute of Bioscience and Human-Technology, (1996). *Human Body Dimensions Data for Ergonomic Design*
306 (p.81). Japan Publication Service, Tokyo.

307

308 Fluent Incorporated, *FIDAP User's Manual*.



Fig.1 Drinking test

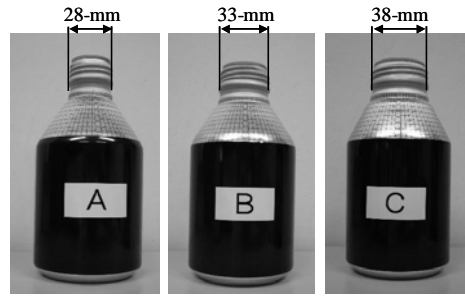


Fig.2 Experimental bottles

(1) Bottle of 28-mm opening

Mark the number with a circle

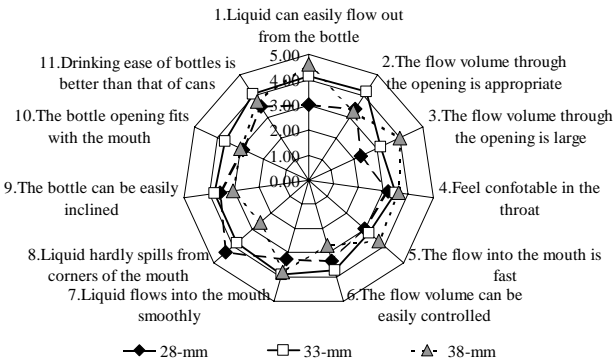
Evaluation items:

1. Liquid can easily flow out from the bottle
2. The flow volume through the opening is appropriate
3. The flow volume through the opening is large
4. Feel comfortable in the throat
5. The flow into the mouth is fast
6. The flow volume can be easily controlled
7. Liquid flows into the mouth smoothly
8. Liquid hardly spills from corners of the mouth
9. The bottle can be easily inclined
10. The bottle opening fits with the mouth
11. Drinking ease of bottles is better than that of cans

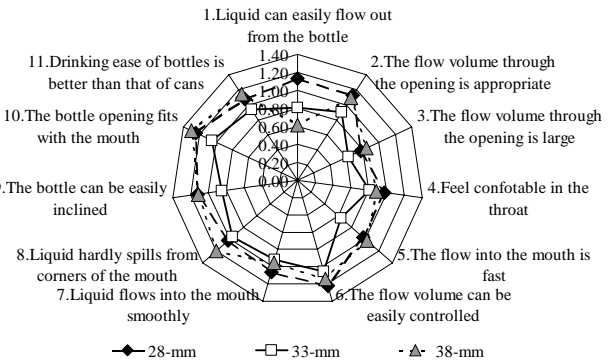
Level:

- | | | | | | |
|---|---|---|---|---|--|
| 5 | 4 | 3 | 2 | 1 | Liquid can hardly flow out from the bottle |
| 5 | 4 | 3 | 2 | 1 | The flow volume through the opening is inappropriate |
| 5 | 4 | 3 | 2 | 1 | The flow volume through the opening is small |
| 5 | 4 | 3 | 2 | 1 | Feel uncomfortable in the throat |
| 5 | 4 | 3 | 2 | 1 | The flow into the mouth is slow |
| 5 | 4 | 3 | 2 | 1 | The flow volume can be hardly controlled |
| 5 | 4 | 3 | 2 | 1 | Liquid flows into the mouth not smoothly |
| 5 | 4 | 3 | 2 | 1 | Liquid easily spills from corners of the mouth |
| 5 | 4 | 3 | 2 | 1 | The bottle can be hardly inclined |
| 5 | 4 | 3 | 2 | 1 | The bottle opening unfits with the mouth |
| 5 | 4 | 3 | 2 | 1 | Drinking ease of bottles is worse than that of cans |

Fig.3 An example of the questionnaire sheets

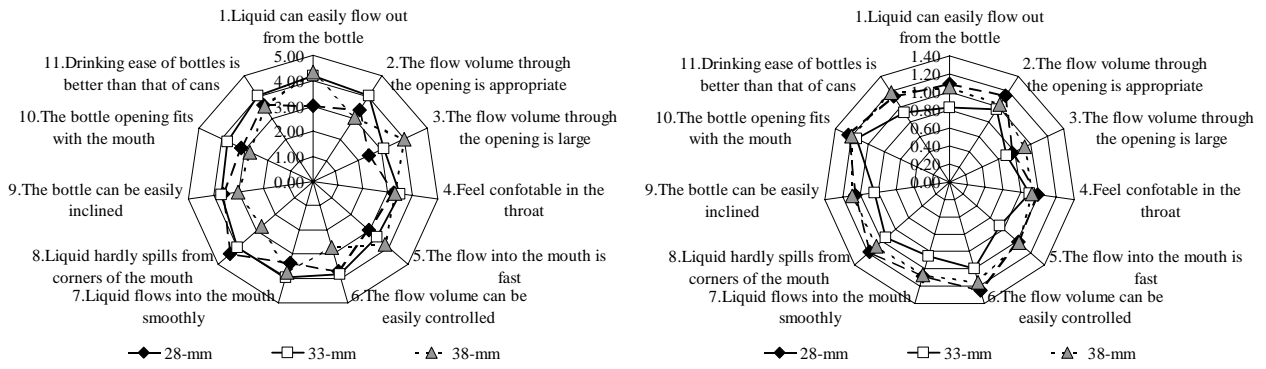


(a) Mean values of 11 items (Green tea)



(b) Standard deviations of 11 items (Green tea)

Fig.4 Evaluation results of questionnaire (Green tea)



319

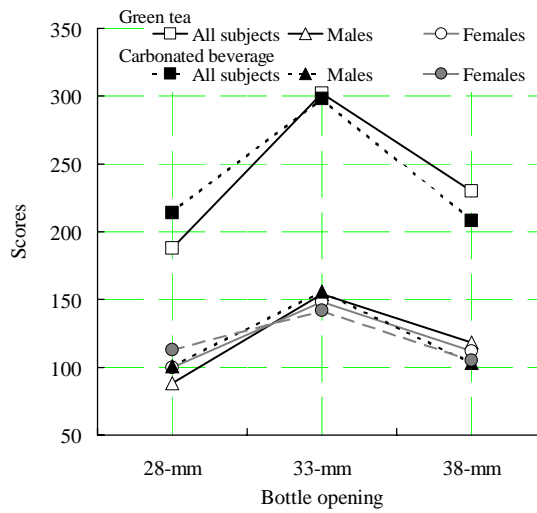
320

(a) Mean values of 11 items (Carbonated beverage) (b) Standard deviations of 11 items (Carbonated beverage)

321

Fig.5 Evaluation results of questionnaire (Carbonated beverage)

322

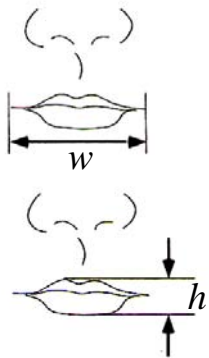


323

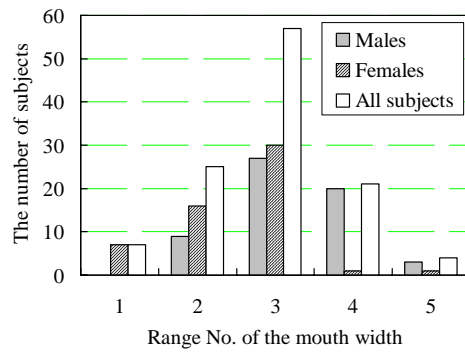
324

Fig.6 Ranking results of drinking ease

325

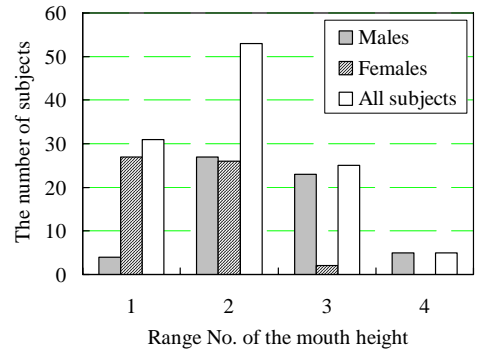


326



(a) Measurement method

(b) Distribution by mouth width



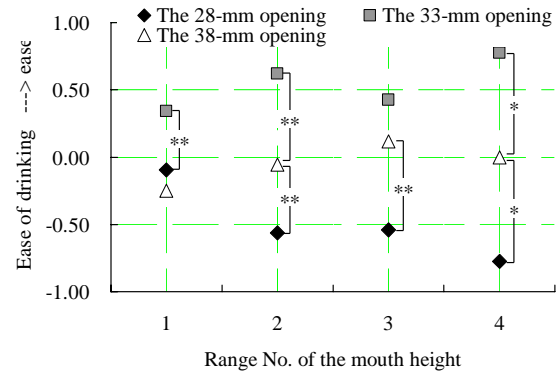
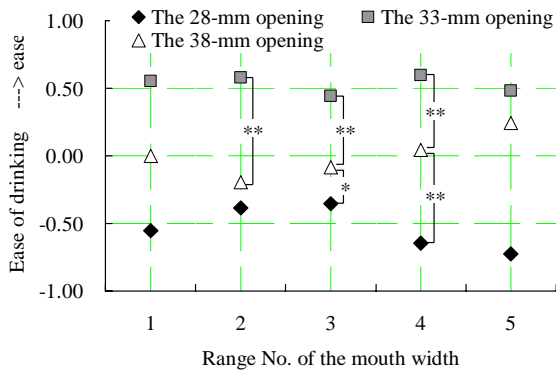
(c) Distribution by mouth height

327

328

Fig.7 Distributions by mouth dimensions

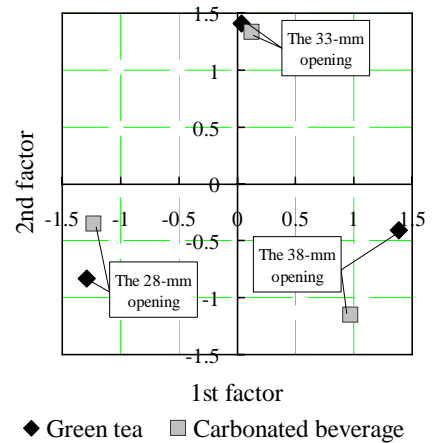
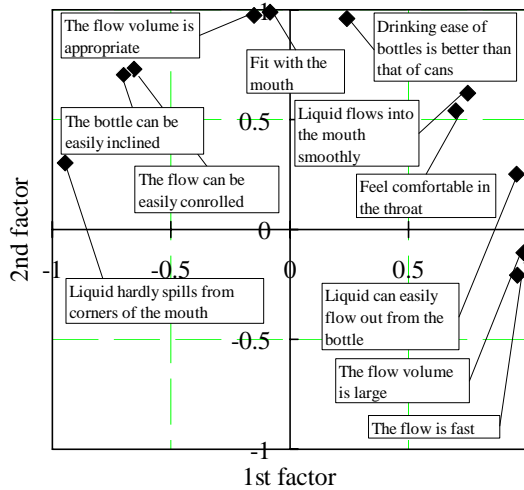
329



(a) Influence of mouth width

(b) Influence of mouth height

Fig.8 Influence of mouth dimensions on drinking ease: ** : $p < 0.01$, * : $p < 0.05$



(a) Factor loadings of 11 evaluation items

(b) Factor scores of three kinds of bottles

Fig.9 Factor analysis results

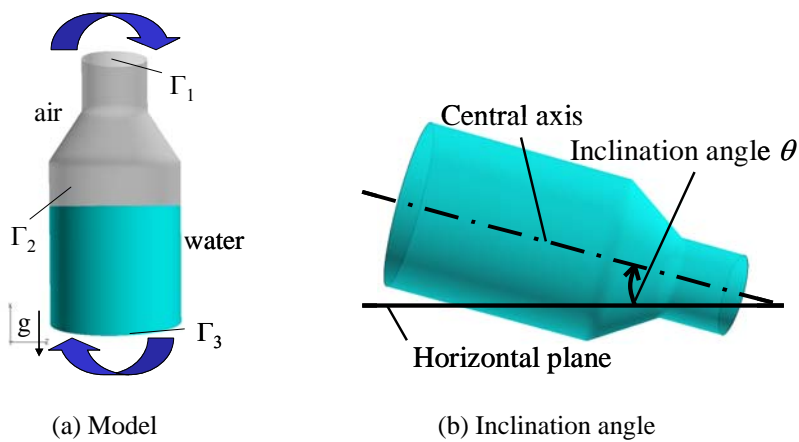


Fig.10 Three dimensional fluid-dynamics analysis model

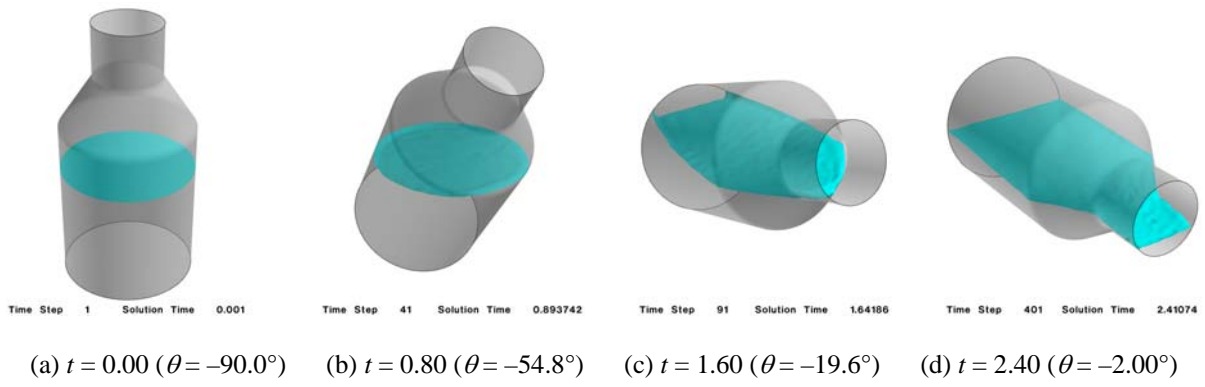


Fig.11 Fluid-dynamics analysis results

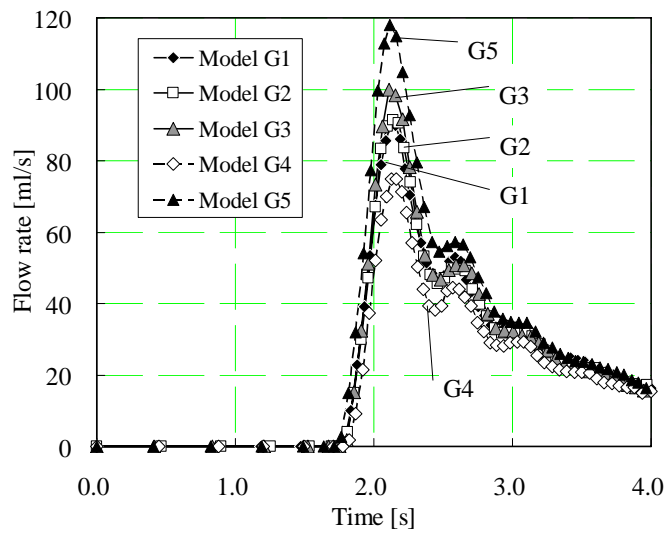


Fig.12 History plots of the flow rate

348

Table 1 Ranking results of drinking ease

349

(a) Green tea

Sample	Number of subjects			Scores
	1st	2nd	3rd	
The 28 mm opening	16	36	68	188
The 33 mm opening	71	40	9	302
The 38 mm opening	33	44	43	230

350

(b) Carbonated beverage

Sample	Number of subjects			Scores
	1st	2nd	3rd	
The 28 mm opening	26	42	52	214
The 33 mm opening	70	38	12	298
The 38 mm opening	24	40	56	208

351

352

Table 2 Factor loadings obtained in the factor analysis

Items	Factor loadings		Communality
	1st factor	2nd factor	
1.Liquid can easily flow out from the bottle	0.96	0.25	0.98
2.The flow volume through the opening is appropriate	-0.15	0.98	0.97
3.The flow volume through the opening is large	0.99	-0.11	0.99
4.Feel comfortable in the throat	0.70	0.54	0.78
5.The flow into the mouth is fast	0.96	-0.21	0.96
6.The flow volume can be easily controlled	-0.66	0.73	0.96
7.Liquid flows into the mouth smoothly	0.75	0.62	0.95
8.Liquid hardly spills from corners of the mouth	-0.95	0.30	0.99
9.The bottle can be easily inclined	-0.70	0.70	0.99
10.The bottle opening fits with the mouth	-0.08	0.99	0.99
11.Drinking ease of bottles is better than that of cans	0.24	0.96	0.98
Contribution quantity	5.77	4.77	10.5
Contribution rate (%)	54.7	45.3	100
Fluctuation rate (%)	52.5	43.4	95.9

353

354

355

356

357

Table 3 Factor scores obtained in the factor analysis

Sample	1st factor	2nd factor
28 mm (Green tea)	-1.29	-0.83
33 mm (Green tea)	0.04	1.41
38 mm (Green tea)	1.39	-0.41
28 mm (Carbonated beverage)	-1.23	-0.35
33 mm (Carbonated beverage)	0.12	1.33
38 mm (Carbonated beverage)	0.97	-1.15

358

359

Table 4 Properties of the fluid-dynamics analysis

Materials	Density [kg/m ³]	Viscosity [Pa·s]
Water	998	1.00×10 ⁻³
Air	1.20	1.82×10 ⁻⁵

360

361

Table 5 Final inclination angles of the fluid-dynamics analysis

Beverage type	Final inclination angle θ_e [deg]		
	28 mm	33 mm	38 mm
Green tea	0.00	-2.00	-4.00
Carbonated beverage	-3.50	-4.00	-6.00

362

363

Table 6 Average rate of flow

Sample	Final inclination angle θ_e [deg]	Start time [s]	End time [s]	Average flow rate [ml/s]
Model G1 (28 mm)	0.00	1.77	2.49	55.1
Model G2 (33 mm)	-2.00	1.79	2.46	57.7
Model G3 (38 mm)	-4.00	1.78	2.48	60.1
Model G4 (28 mm)	-2.00	1.80	2.42	46.7
Model G5 (38 mm)	-2.00	1.74	2.47	70.8
Model C1 (28 mm)	-3.50	1.83	2.42	40.1
Model C2 (33 mm)	-4.00	1.82	2.46	47.2
Model C3 (38 mm)	-6.00	1.82	2.46	49.4

364