10th World Congress on Structural and Multidisciplinary Optimization
May 19 -24, 2013, Orlando, Florida, USA

Optimization of Deep Drawing Process for Circular Cup Forming

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1. Abstract
Circular cup drawing is the first forming process for forming the body of two-piece aluminum beverage cans / bottles. This paper has investigated optimum drawing process by changing circumferentially the blank holder forces, to draw earless circular cups from anisotropic blank sheet. At first, a drawing process analysis model has been made using the finite element method, and the circular cup drawing simulation has been performed. Forming simulation results on ear profiles have been compared to experimental observations and have been confirmed that the analysis model is acceptable for further studies on earing reduction. Cup drawing process analysis model with blank holder force distributed circumferentially region by region, has then been built to observe the effects on earing reduction. At last, the optimum design has been performed to obtain the optimum number of regions and optimum blank holder force for each region.
2. Keywords: Aluminum Beverage Cans & Bottles, Deep Drawing, Earing, Sheet Forming Simulations, Forming Process Optimization.

3. Introduction
Deep drawing process is frequently used in the packaging industry, the automotive industry and the household appliances industry. In a deep drawing process, an initially flat sheet or a blank, usually constrained by a blank-holder, is forced into and /or through a die by means of a punch to form the final shape of components. Circular cup drawing is the most basic process among the deep drawing processes.
In the deep drawing process, deformation defects such as fracture and wrinkling have been found due to large deformation. Moreover, earing(Fig.1) is also one of the major defects observed in the circular cup drawing from anisotropic blank sheet. The blank is anisotropic due to the directionality of plastic properties produced by rolling and other primary working process. One of the ways that directionality shows up in deep drawing is the phenomenon of earing. It is the formation of a wavy edge on the top of a drawn cup that necessitates extensive trimming to produce a cup with uniform height.
Circular cup drawing is the first forming process for forming the body of two-piece aluminum beverage cans / bottles (Fig.2). The two-piece aluminum beverage can/bottle consists of two pieces, one body piece (a cylinder with a toroidal bottom) and one end/cap piece. Forming process optimization of the end shell has been performed [1]. Forming process of the body of the can/bottle is shown in Fig. 3. The thin sheet blank is drawn into a shallow cup, and the drawn cup is then formed into a cup with smaller radius, longer length and thinner wall-thickness by redrawing & ironing processes. Before the cup is formed into the final shape of the can/bottle body, the top of the cup with ears is trimmed to reach a uniform top. To save materials and to get uniform mechanical property of the cup wall, less amount of trimming or earless cups are expected.

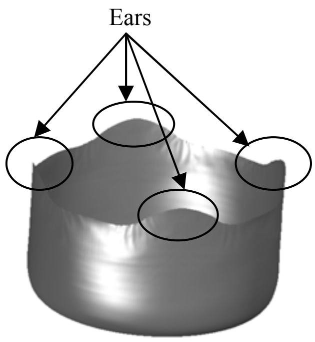


Figure 1 Drawn cup with ears

(a) Cans

(b) Bottles

Figure 2 Two-piece aluminum beverage cans and bottles.

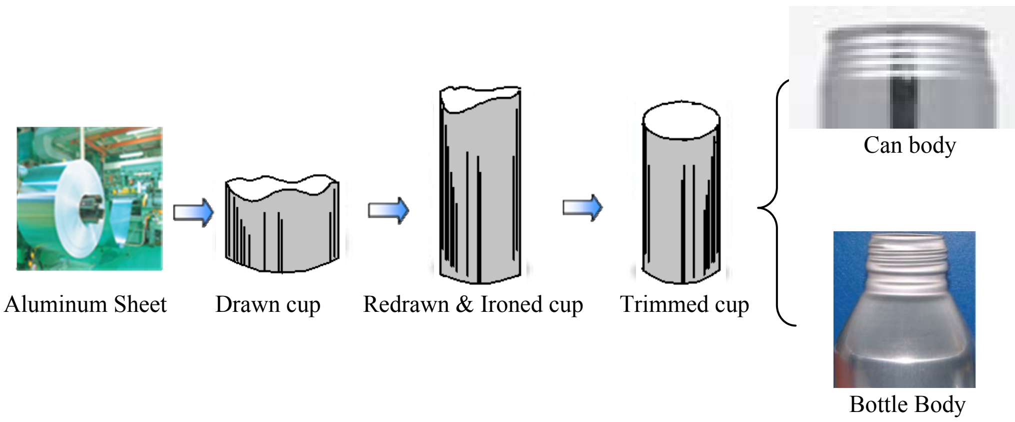


Figure 3 Forming processes of the body of two-piece beverage cans and bottles.

Anisotropy of the blank has an important effect on the earing profile in a drawn cup, that's why can-stock manufacturers have been made efforts to improve anisotropy of the roll forming sheet. However, anisotropy of the roll forming sheet cannot be removed completely. On the other hand, many investigations have been carried out on initial non-circular blank shape design for an earless circular cup in cup drawing [2]. However, there are some demerits in using the non-circular blank. For example, blanks produced by different manufacturing process may have different anisotropy, hence different optimum non-circular shape for the earless cup. And non-circular tools used to cut the non-circular blank are more expensive.

Blank holder force is one of important factors to control the drawing process. To avoid fracture and wrinkling, numerous researches have been done numerically and experimentally, to obtain optimum variable blank holder force trajectory or to control blank holder force region by region [3, 4].
This paper investigates optimum drawing process by changing circumferentially the blank holder force, to draw the circular blank into earless circular cups. At first, a drawing process analysis model is made using the finite element method, and the circular cup drawing simulation is performed. Forming simulation results on ear profiles are compared to experimental observations. And then, a drawing process analysis model with different blank holder force circumferentially is built to observe effects on earing. At last, the optimum design is performed.

4. Cup Forming Simulation
The tooling geometry for drawing the circular cup given in the numisheet’2011 benchmark [5] is adopted for finite element model building. Figure 4 shows the photo of the drawn cup and dimensions of the tools. The Outer radius of the punch R_p = 22.86 mm, the inner radius of the draw die R_d = 23.368mm, the round corner radius and angle of the punch are r_{p2} = 2.229 mm, 0.873 Deg., respectively. The round corner radius of the draw die r_d = 1.905 mm. The radius of the blank R_b = 23.114 mm. The thickness of the blank is 0.208mm. Material of blank is aluminum with Young’s modulus E = 68.6 GPa, Poisson’s ratio v = 0.33 and the yielding stress σ_0 = 0.28 GPa, mass density 2.7e^{-6} kg/mm^3. r-values are r_0 = 0.354, r_{45} = 1.069, r_{90} = 1.396.
Cup forming simulation is performed using explicit finite element program, LS-DYNA, based on three dimensional models. All tools were assumed to be rigid. To save computational time, a quarter of the circular blank was modeled with quadrilateral shell elements, as shown in Fig. 5. Frictional coefficient between tools and the blank is assumed to be 0.05.
The drawn cup simulated is shown in Fig.6 and the ear profile is compared with experimental measurements. It is concluded that the finite element model is acceptable for studying the effect on earing reduction by changing circumferentially blank holder force.

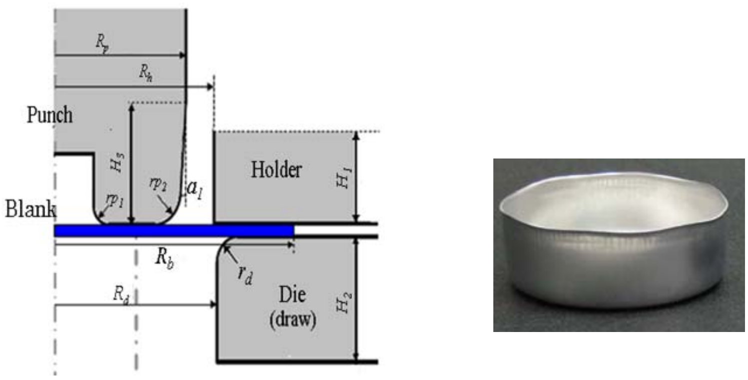


Figure 4 Tools and their dimensions for the circular cup drawing [5]

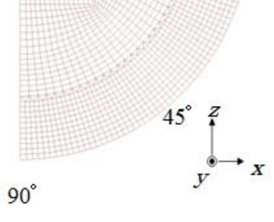


Figure 5 Finite element model of circular blank (1/4 Model)

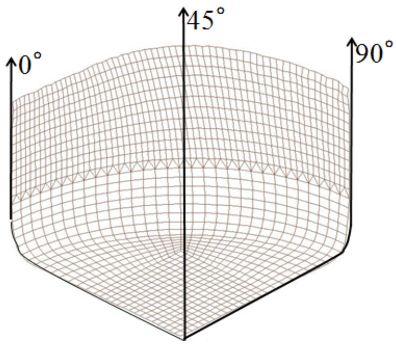


Figure 6 Cup drawing simulation results

5. Optimum Design of Blank Holder Force Distribution

Optimum design of blank holder force distribution is carried out for forming the cup of a new can. The Outer radius of the punch R_p = 47.4 mm, the inner radius of the draw die R_d = 47.9mm, the radius of the blank is R_b = 78.7mm. The finite element model is shown in Fig.7. r-values of the material are assumed to be r_0 = 0.34, r_{45} = 0.88, r_{90} = 0.65.

As shown in Fig.8, two kinds of blank holder forces, uniform blank holder force and distributed blank holder force, are observed. Distributed blank holder force may be divided circumferentially into more than two regions for a 1/4 model. Figure 9 (a), (b), (c) show the drawn cups when uniform blank holder forces are 0.5kN, 15.0kN and 19.0kN, respectively. It's clear that if the blank holder force is too small, wrinkles appear, while if the blank force is too large, fracture occurs.

The distributed blank holder force is designed by decreasing the blank holder force at region where earing amplitude is relatively large and by increasing the blank holder force at region where the amplitude is relatively small, as shown in Fig. 10. The optimum design of the number of regions divided circumferentially and the value of the blank holder force for each region is performed. Optimum design results in Figure 11 show that the earing amplitude is reduced by adding blank holder forces varied region by region.

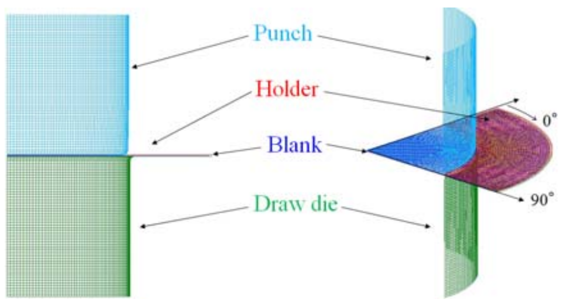


Fig.7 Cup drawing process analysis model

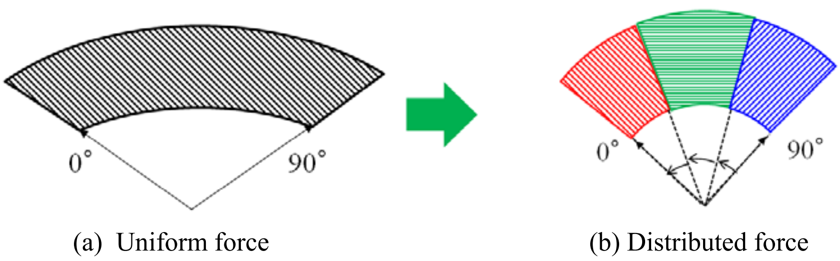
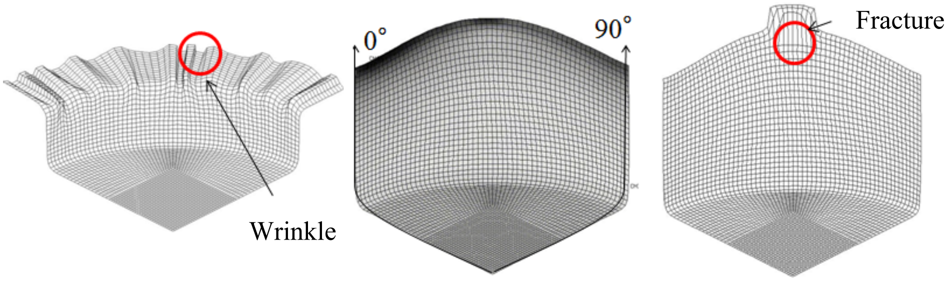


Fig.8 Blank holder force applying method



(a) 0.5kN (b) 15.0kN (c) 19.0kN

Figure 9 Drawn cups under various uniform blank holder force

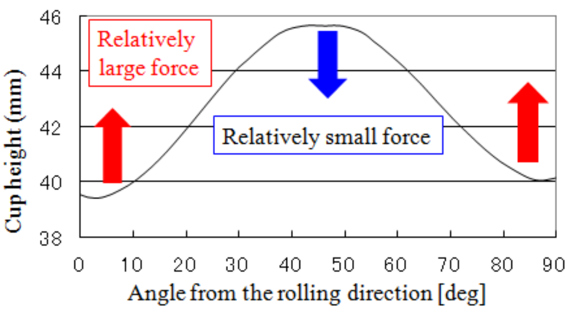


Figure 10 Distributed blank holder force design

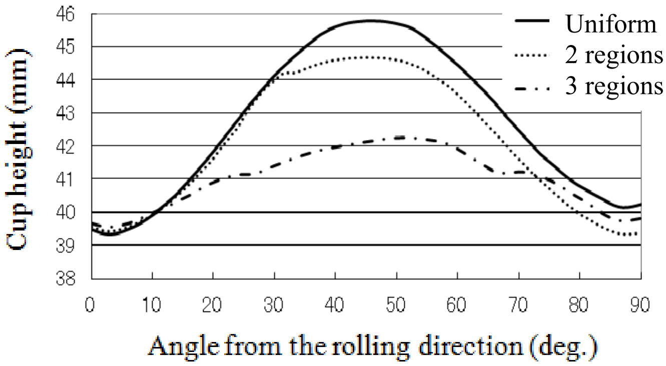


Figure 11 Optimum design of distributed blank holder force

6. Conclusions

This paper investigated optimum drawing process by changing circumferentially the blank holder forces, to draw the circular blank into earless circular cup. At first, a drawing process analysis model was built using the finite element method, and the circular cup drawing simulation was performed. Forming simulation results on ear profiles were compared to experimental observations and were confirmed that the analysis model is acceptable for further studies on earing reduction. Cup drawing process analysis model with distributed blank holder force varied circumferentially region by region, was then built to observe effects on earing. At last, the optimum design was performed to obtain the optimum number of regions and optimum blank holder force for each region.

7. References

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