Simulation and Analysis of the Beverage Can Necking Process Using LS-DYNA

Jordan-Cordera, A. & Miranda-Valenzuela, J.C.
Mechanical Engineering Department
ITESM Campus Toluca
Eduardo Monroy Cardenas 2000, Toluca 50110 México
jmiranda@itesm.mx

Abstract

Due to their large production quantities, beverage cans have been the subject of many studies. Such studies have as objectives to increase the level of understanding of the structural behavior of the can as well as its manufacturing process. In this work, the necking process is studied by means of a parameter response study carried out with the help of LS-DYNA. Even when the necking process is affected by many factors including can geometry, material properties, tool geometry, friction coefficient between the tools and the can, punch speed, etc., in this study only four variables are taken into account: friction coefficient, punch speed, can thickness and can radius.

Introduction

Aluminum beverage cans have been in the market for many years now and had suffered a series of improvements over the years, especially in terms of the net material needed to manufacture them. As several million aluminum cans are manufactured each day, the search of thinner sidewalls, reduced neck and base diameters in order to reduce costs has been a continuous effort for over three decades. In consequence, many authors have devoted time to study the structural behavior of the can as well as its manufacturing process.

Regarding its structural behavior, Dick, Smith and Myers (1992) studied the drop resistance of cans. Later, Dick (1994) studied the axial buckling of beverage can sidewalls. Bielenberg, Magner and Reid (2002) compared the results of numerical and experimental data to understand the buckling mechanisms of indented and deformed aluminum cans. In the same year, Coon, Anugonda and Reid, developed a model to analyze the structural behavior of an aluminum beverage can subjected to a piercing load applied to the sidewall. The manufacturing process has been studied by MacEwen *et al*. (2000) who developed Finite Elements models understand the forming and performance of aluminum beverage cans. Dick (2002) also developed a Finite Elements model to improve the beverage can redraw process.

In this work, following a similar procedure to the one proposed by Dick (2002), the Finite Elements model is developed with the help of LS-DYNA to understand the beverage can necking process. With this goal in mind, a parameter response study was carried out including as factors the can radius, the thickness of the can wall, the punch speed and the friction coefficient.

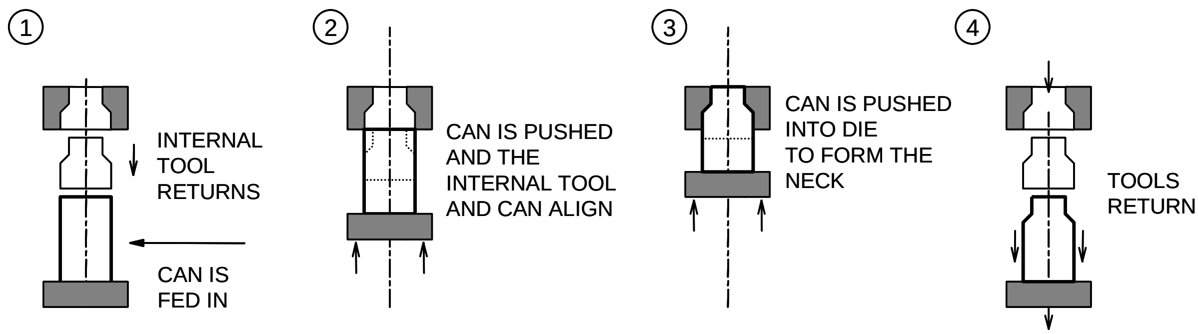

Figure 1. First step of the neck forming process.

The necking process

Necking of thin walled cylinders is generally carried out with one or more of the following objectives: allow the assembly of a cap of smaller diameter, increase the stiffness of the cylinder or to facilitate the storage of the product. In most occasions, the process of forming a neck is done in cans made out of steel, aluminum or tin and is performed in several stages to minimize the appearance of wrinkles, fractures or both. As several stages are needed in order to create the neck, this process is the bottleneck of can production lines. It is also the one that generally produces the largest amount of defects in the product. In aluminum cans, this necking process is carried out after the can has been redraw and painted.

Each stage of the necking process consists of 4 steps as depicted in Figure 1. First, the can is fed in and the punch that will be used later to form the neck returns to its original position. Second, the can is pushed towards the die aligning it with the punch. Next, can and punch are pushed together to form the neck. Finally, the pushing tool, as well as the punch, returns to their original positions freeing the can.

The above process is repeated using progressively smaller diameters of punch and dies in order to obtain the final desired shape. During the different deformation stages, is not uncommon for wrinkles to appear in the neck of the can. These wrinkles are believed to be caused by the thinning of the can sidewall either at the redraw process or at the necking process itself.

Wrinkle factor calculation

To asses the severity of the wrinkling at the last stage of the necking process, a wrinkle factor similar to the one proposed by Dick (2002) was used. Here, the wrinkle factor is calculated as follows. First, the position of each node at a fixed height is expressed in polar coordinates. The average radius at this fixed height is used to calculate the arc length. Next, the real arc length is calculated and the difference between the two is computed. This difference, expressed in percentage, is used as the wrinkle factor. Ideally, no wrinkling will yield a wrinkle factor of zero. If the severity of the wrinkling increases, the value of the wrinkle factor will increase accordingly.

Finite Elements Simulation

In order to reduce the complexity of the model, some simplifications and considerations were taken into account. First, the can was considered to be unpainted. The thermal effects and tool deformation were neglected, the friction coefficient was considered constant and the punch velocity was also considered to be constant during the entire displacement path. The residual stresses from previous forming steps were no taken into account. Finally, in this first approach, it was assumed that there was no localized thinning in the can sidewall.

A finite element model was created using the following information. The geometry used was generated by means of tool profiles provided by a local can manufacturing company. These profiles provided the dimensions necessary to reproduce the profiles of the 14 different pairs of punch and dies in a CAD program. All 28 profiles together with the line representing the can were later exported to the *eta/FEMB-PC Finite Element Model Builder Version 27* where with the use of the revolution function the surfaces shown in Figure 2 were generated.

The meshes for the FE model were created from the surfaces generated previously. The element selected was the 4-node shell with thickness. Due to limitations in the license used, the mesh size was set on 0.1 inches giving the FE model shown in Figure 3. This model has 7339 elements, (7292 quads and 47 trias) and 8273 nodes.

The material properties used for this analysis are shown in Table 1. Using this information the material model used for the rigid part was 20.1 * MAT_RIGID and for the sheet metal part was 3.1 *MAT_PLASTIC_KINEMATIC with the isotropic hardening option. The property that was created and assigned to the meshes is Shells, the element formulation that was used is #2 Belytschko-Tsay. Five integration points through the thickness of shell were used. The initial thickness defined is 0.0058 in.

Due to the nature of the process studied, contact is one of the most important characteristics of the analysis. The contact type assigned to the model was 3-dimensional Contact forming surface to surface. To create the model, 14 pairs of contact cards were specified, each pair corresponding to one of the fourteen forming stages. Because of the multi-stage condition it was necessary to use the birth and death function, which information is shown in Table 2. The analysis termination time was set on 0.882 s.

Table 1. Material Properties for the metal sheet

Material	Aluminum 31xx
Material Model	*MAT_PLASTIC_KINEMATIC
Mass density	$9.83X10^{-2}$
Young Modulus	$10X10^{6}$ psi
Poisson´s ratio	0.3
Yield stress	37700 psi
Plastic hardening modulus	$10x10^{4}$
Hardening parameter	1

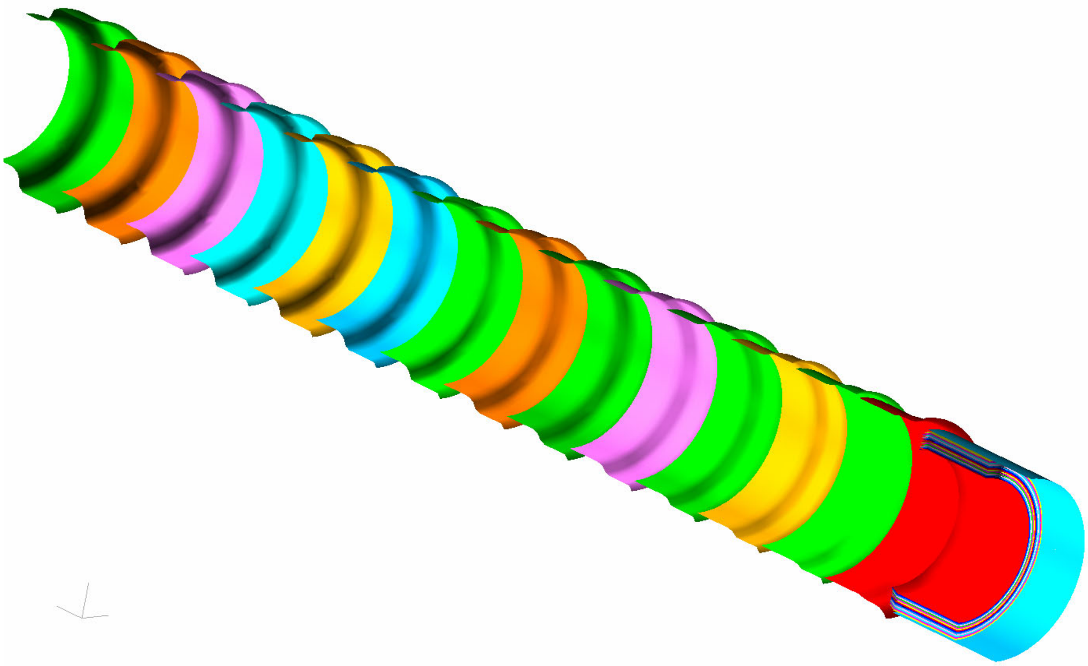

Figure 2. Surfaces generated using ETA preprocessor.

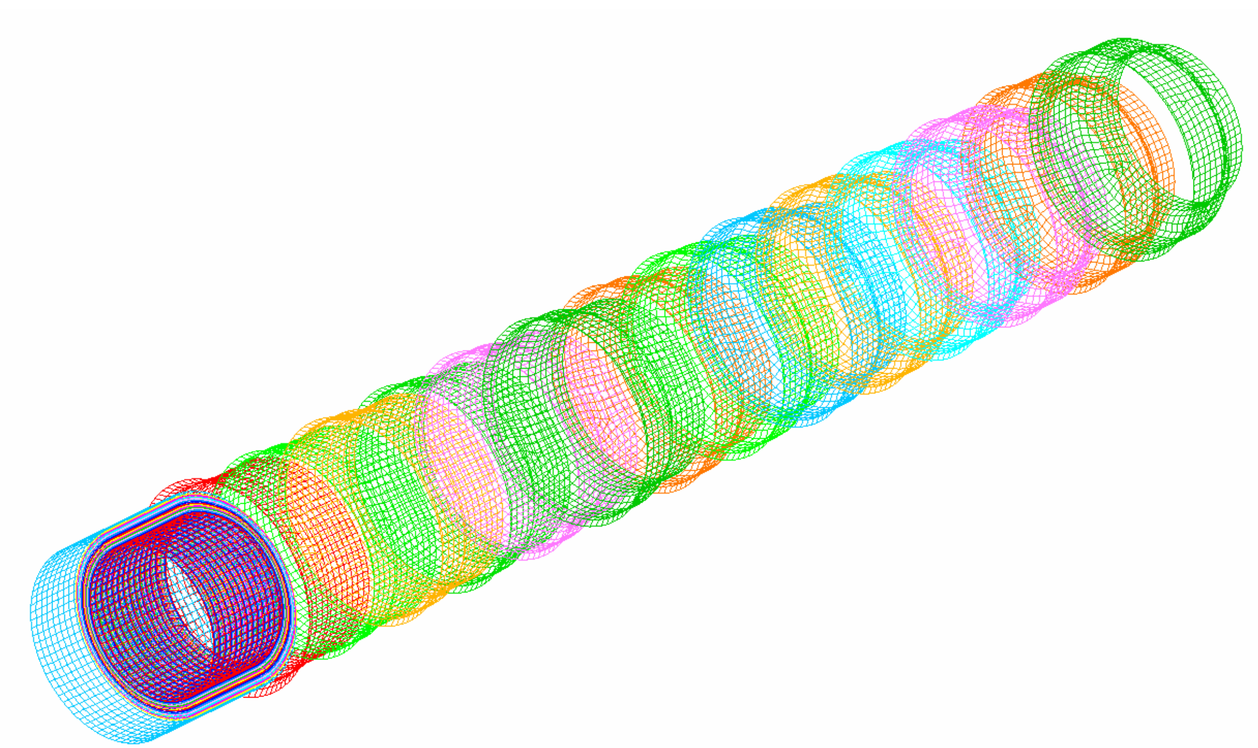

Figure 3. Finite element Mesh of the model

Table 2. Birth and death times for the different forming stages for a punch speed of 20 in/s.

Forming stage	Birth time	Death time
1	0	0.063
2	0.063	0.126
3	0.126	0.189
4	0.189	0.252
5	0.252	0.315
6	0.315	0.378
7	0.378	0.441
8	0.441	0.504
9	0.504	0.567
10	0.567	0.63
11	0.63	0.693
12	0.693	0.756
13	0.756	0.819
14	0.819	0.882

Table 3. Displacement as a function of time for a punch speed of 20 in/s.

Step	Time (s)	Displacement (in)
-	0	0
1	0.063	1.26
2	0.126	2.52
3	0.189	3.78
4	0.252	5.04
5	0.315	6.3
6	0.378	7.56
7	0.441	8.82
8	0.504	10.08
9	0.567	11.34
10	0.63	12.6
11	0.693	13.86
12	0.756	15.12
13	0.819	16.38
14	0.882	17.64

The boundary conditions for the model were defined as follows: prescribed motion using the information in the Table 3 applied on the nodes that correspond to all the punches and the cylinder. Also, single point constrains were applied due to the fact that the model built is ¼ of the structure. The initial condition defined was velocity which was applied on the nodes that correspond to the punches and the cylinder. The initial velocity defined was 20 in/s.

Parameter Response Study

The necking process can be affected by many factors including can geometry, tool geometry, material properties, friction coefficient between tools and can, contact conditions and punch speed. Although the FE model created can be used to study the influence of all these factors, not all are equally easy controlled in the production line. Hence, it was decided to limit the parameter response study to four variables: friction coefficient, punch speed, can thickness and can radius.

To carry out the parameter response study, each of these four parameters was modified keeping the other three unchanged. The values used to carry out the parameter response study are shown in Table 4. For each factor, five different values were tested. On each case, the values for the factor were modified keeping the other three parameters unchanged. All values are similar to those found in the production line with the exception of those for the friction coefficient which values were estimated.

Table 4. Values for the parameter response study.

Analysis	F.C	P.V (in/s)	T (in)	R (in)
1	0.08	20	0.0058	1.3
2	0.09	20	0.0058	1.3
3	0.1	20	0.0058	1.3
4	0.11	20	0.0058	1.3
5	0.12	20	0.0058	1.3
6	0.1	20	0.0058	1.3
7	0.1	28	0.0058	1.3
8	0.1	38	0.0058	1.3
9	0.1	46	0.0058	1.3
10	0.1	54	0.0058	1.3
11	0.1	20	0.00575	1.3
12	0.1	20	0.00585	1.3
13	0.1	20	0.00595	1.3
14	0.1	20	0.00605	1.3
15	0.1	20	0.00615	1.3
16	0.1	20	0.0058	1.2
17	0.1	20	0.0058	1.25
18	0.1	20	0.0058	1.3
19	0.1	20	0.0058	1.35
20	0.1	20	0.0058	1.4

Results

As a result of each simulation run, the final shape of the can neck was obtained together with information regarding its final thickness as shown in Figure 4. With the results obtained, the wrinkle factor was computed. The results obtained for each parameter are discussed next.

Friction coefficient

The friction coefficient was varied from 0.08 to 0.12. The variation influence of the friction coefficient over the wrinkle factor and the final maximum thickness is shown in Figure 5. This figure shows that the wrinkle factor increases as the friction coefficient increases. This is especially evident for the value of 0.12. It can also be observed that as the friction coefficient increases the final thickness values also increase.

Can radius

The can radius can be controlled with the tool diameters of the preceding operation to the necking process. The value for the can radius was varied from 1.2 to 1.4. As shown in Figure 6, the values for which the wrinkle factor is minimum are between 1.25 and 1.35 in. and start increasing as the radius decreases or increases above these limits. From the thickness plot shown, it can be observed that as the radius increases the final thickness increases as well. This is result of more material being deformed into the same shape.

Wall thickness

The influence of the wall thickness was studied varying its value from .00575 to .00615 inches. The results are presented in the Figure 7 in which it can be seen that only for the minimum value the wrinkle factor is relatively high. For the other thickness values the wrinkle factor does not change in a significant way. As it was expected the final thickness is increased if the initial thickness is increased.

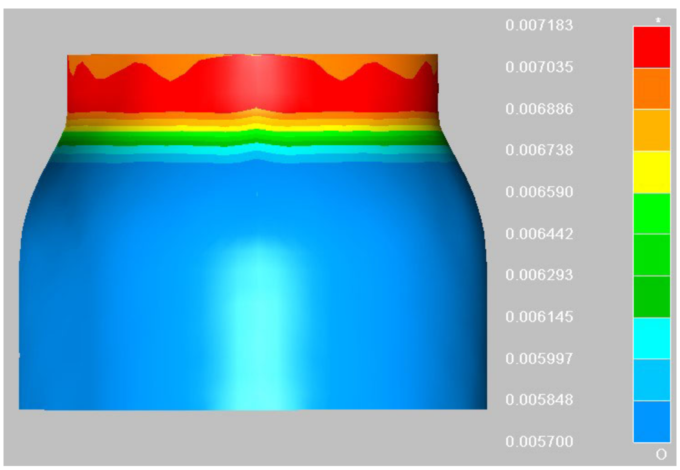

Figure 4. Final shape of the necked can showing final thickness contours.

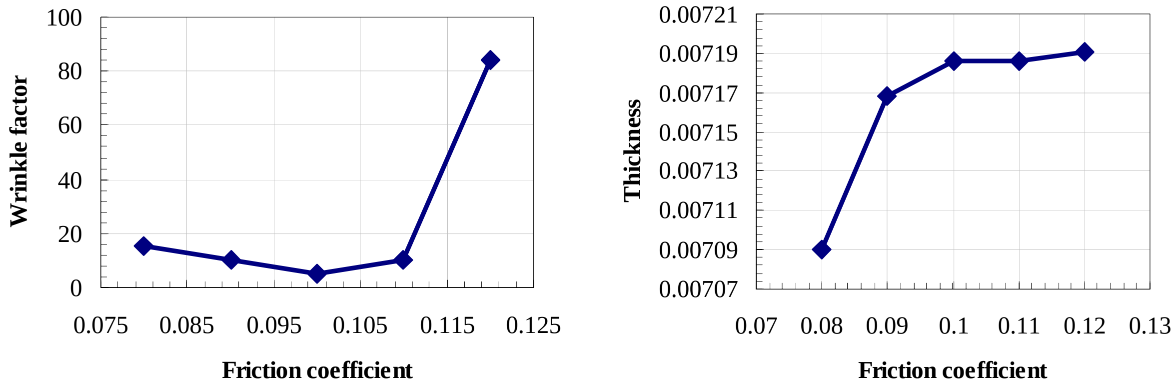

Figure 5. Effect of the friction coefficient on the predicted wrinkling factor and the maximum value of the final thickness.

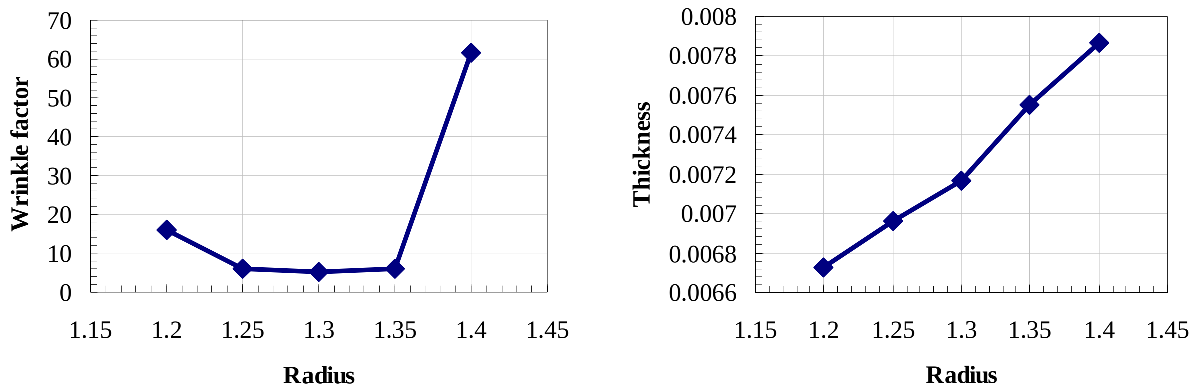

Figure 6. Effect of the can radius on the predicted wrinkling factor and the maximum value of the final thickness.

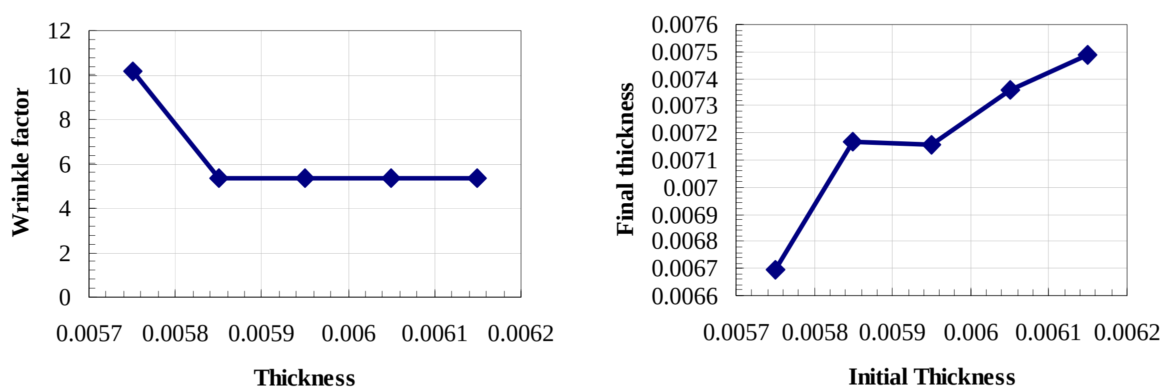

Figure 7. Effect of the initial thickness on the predicted wrinkling factor and the maximum value for the final thickness.

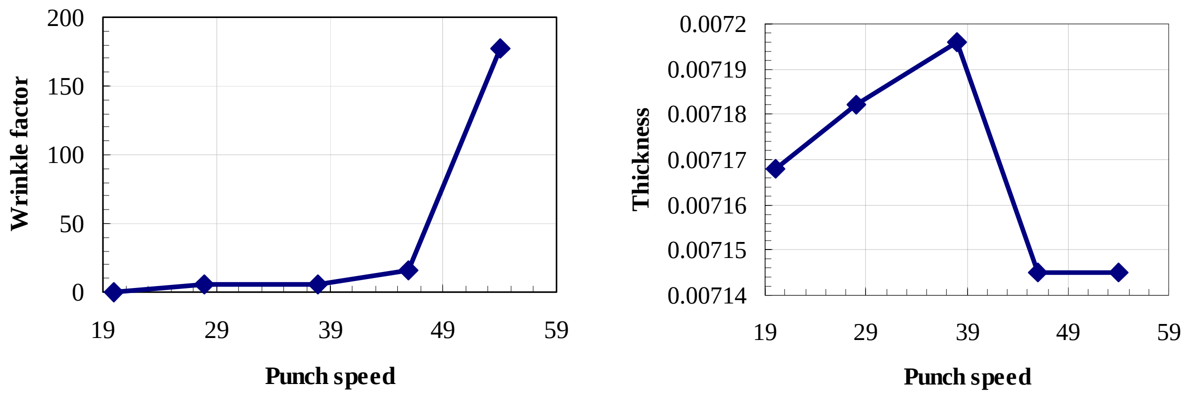

Figure 8. Effect of the punch speed on the predicted wrinkling factor and the maximum value for the final thickness.

Punch speed

The analyses carried out in order to determine the influence of the punch speed over the wrinkling factor were using punch speeds ranging from 20 to 56 in/s. As it is shown in Figure 8, while the punch speed increases the wrinkle factor value also increases. The results obtained also indicate that as the punch speed increases, especially over 39 in/s, the thickness values decrease due to the fact of large wrinkles appearing in the neck.

Conclusions

A Finite Element model was developed to simulate the beverage can necking process. The model was used to carry out a parameter response study to evaluate the influence of the punch speed, friction coefficient, can radius and can sidewall thickness in the formation of wrinkles. From the numerical experiments it was observed that as the friction coefficient increases, the wrinkle factor and the final thickness also increase. It was also found that the increase of the initial wall thickness does not seems to affect the formation of wrinkles in a significant way as long as the initial can sidewall is not below 0.00575 in. The can radius for which the wrinkle factor is minimum are between 1.25 and 1.35 in. and start increasing as the radius decreases or increases above these limits. Finally, for the punch speed it was observed that as the punch speed increases, the severity of the wrinkles also increases.

As next step of this work, the simulation of cans which sidewall presents two or more areas with different thickness will be considered in order to take into account the effect of the redraw process.

Acknowledgements

The kind support of Fabricas Monterrey planta Toluca for the development of this work is hereby gratefully acknowledge.

References

Bielenberg, R.W., Magner, S.H. and Reid, J.D. (2002). “Sidewall indentation and buckling of deformed aluminum beverage cans”. *7th International LS-DYNA Users conference*. Dearborn, MI, USA.

Coon, B.A., Anugonda, P. and Reid, J.D. (2002) “Piercing of aluminum beverage cans”. *7th International LS-DYNA Users conference*. Dearborn, MI, USA.

Dick, R. E. (2002) “Improvements to the beverage can redraw process using LS-DYNA”. *7th International LS-DYNA Users conference*. Dearborn, MI, USA.

Dick, R.E., Smith, G.L. and Myers. (1992) “Aluminum beverage cans with improved drop resistance”. *SME International Can Manufacturing Technology Clinic*. Rosemont, IL.

LS-DYNA Keyword User´s Manual version 960 (2001). Livermore Software Technology Corporation, California.

MacEwen, S.R., Langille, A., Hamstra, P. and Wu, P.D. (2000) “Understanding the forming and performance of aluminum beverage cans through Finite Element Modeling”. *Mathematical modeling in metal processing and manufacturing – COM 2000*, Ottawa, Canada.