Numerical analysis of relationship between height and geometry of bottom of a beverage can and its resistance to increase in internal pressure

Artur Rękas[1], Tomasz Latos[1], Łukasz Brodawka[2], Maciej Kociołek[2], Michał Siedlik[2],
Robert Budzyn[2], Marcin Fijałkowski[2]

[1]AGH University of Science and Technology
[2]Can-Pack S.A.

1 Abstract

This work presents results obtained from numerical analysis of dome reversal pressure test with the use of finite element method. Dome reversal pressure test is one of crucial quality tests required of such products as beverage cans. It gives information about resistance of a bottom in conditions of increased internal pressure. The information is important for both producers of carbonated beverages and for final users. The test identifies the maximum internal pressure which does not cause reversal buckling of a dome. To conduct analyses of the test, a separate numerical module was created. The module is integrated with LS-Dyna Solver. The analyzed geometries of a bottom were modelled in Dynaform 5.9.1 with the use of LS-Dyna too. The numerical simulations are aimed at analyzing the influence of geometry and height of a bottom of a cylindrical drawpiece on its performance in dome reversal pressure test. Another point of interest in the analysis was the influence of the friction factor and velocity of a punch on forming a bottom and its results during a dome reversal pressure test. Taking into account the character of the dome reversal pressure test, these forming parameters cause a change in material flow and thickness distribution on a dome which influences final resistance to internal pressure. The material used in the analysis was 3104 aluminum work hardened to H19 temper. The comparison was conducted on 2 thicknesses of input stripes: 0.250 and 0.241 mm. The module used in the analysis included a full history of deformation that resulted from preceding simulations of drawing and redrawing.

Keywords: Finite element analysis, dome forming, dome reversal pressure, aluminum alloy, thin-wall drawpiece, LS-Dyna

2 Introduction

Aluminum beverage cans are one of the most widely used packaging for all kinds of drinks. In recent years, from a consumer’s perspective, appearance of a can has not been drastically changed in terms of its functionality. Although its diameter or volume have been being modified, the overall appearance of cans is similar. However, when construction of a can and input material for production are taken into consideration, can producers are constantly trying to improve their structure and simultaneously economize material by reducing its thickness. Such changes have a significant impact on quality parameters of cans defined by customers - beverage producers. The dome reversal pressure test is one of the most important qualifying tests for such products as beverage cans. It gives information about resistance of a bottom geometry to increasing pressure inside the packaging. This parameter is important for both manufacturers of carbonated beverages and also final users. The dome reversal pressure test checks what pressure in the bottom of the sphere causes its reversing to the other side (outside).

A lot of research is devoted to optimization of forming cans, individual steps of the process or specific methods of testing the final product. In the analyses, several stages of beverage can manufacturing process were analyzed. These are: the operation of redrawing the cup [1], ironing [2], optimization of forming the bottom [3] and the operation of shaping a neck of a can body [4]. When it comes to quality, research of tests like can piercing, side-wall buckling was performed [5, 6]. In the study [7], the impact of the bottom base profile of beverage cans from steel sheets of various thicknesses on their performance in dome reversal pressure test was analyzed.

This study is focused on numerical analyses of influence of height and geometry of the bottom on bottom reversal pressure, which is qualification test for beverage cans. The actual test is carried out on a fully formed can body. However, in order to simplify the model in the numerical analysis, the bottom after drawing and redrawing was tested. When it comes to physical deformation, this simplification is equal to the physical model of a bottom of a can because during the actual production, the properties of feed material in a bottom part do not change until the final operation, when bottom is shaped. In contrast to the study [7], the material which is actually and currently used in production was taken into consideration. What is more, during shaping the bottom, an additional operation was applied, that is forming of the reversal wall (reforming). The operation is also used in the actual can production technology.

3 Dome Forming - Finite Element Analysis

The analyzed object is a redrawn cup with a formed bottom after an additional reforming operation. To prepare such a bottom, it was first necessary to model it properly. In commercial practice a can forming process is multistage (Fig. 1) and the process of forming the dome is run on a horizontal press - Bodymaker (represented. Fig. 2). However, in the calculations, a simplification was used and only basic operations such as: drawing a cup from a flat sheet, redrawing a cup and forming the bottom were used (converted to Fig. 2 (right) from [8]).

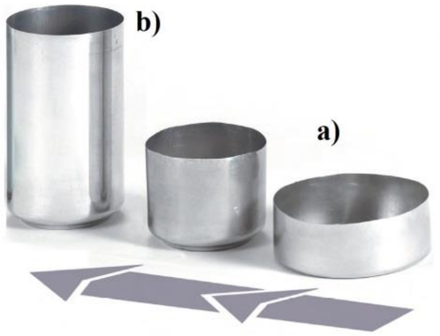

Fig.1: Steps in production process of Al beverage cans, (a) a deep-drawn cup and (b) a trimmed can [8]

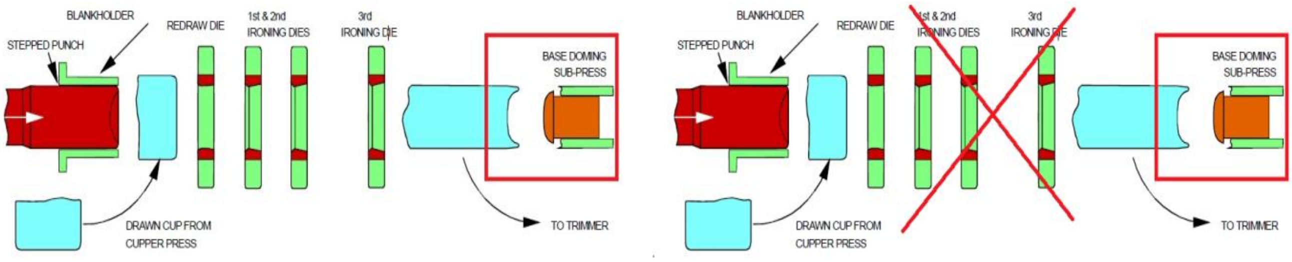

Fig.2: Real manufacturing process (left) and process used in simulations (right) [8]

To shape a bottom, a tool kit consisting of a domer die, a clamp ring and a punch is used (shown in Fig 3). The additional reforming operation is conducted with a roll which moves rotationally and forms the reversal wall. The most important geometrical dimensions of formed bottoms are shown in Fig. 4.

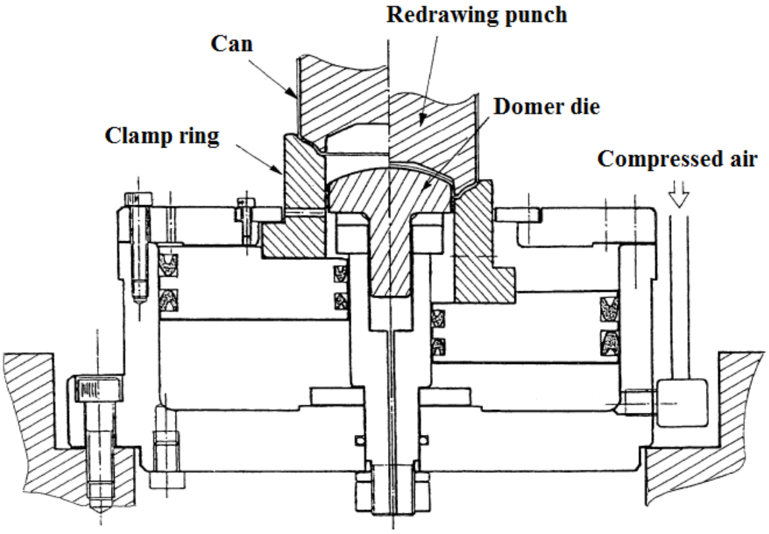

Fig.3: Schematic view of a dome forming toolkit [7]

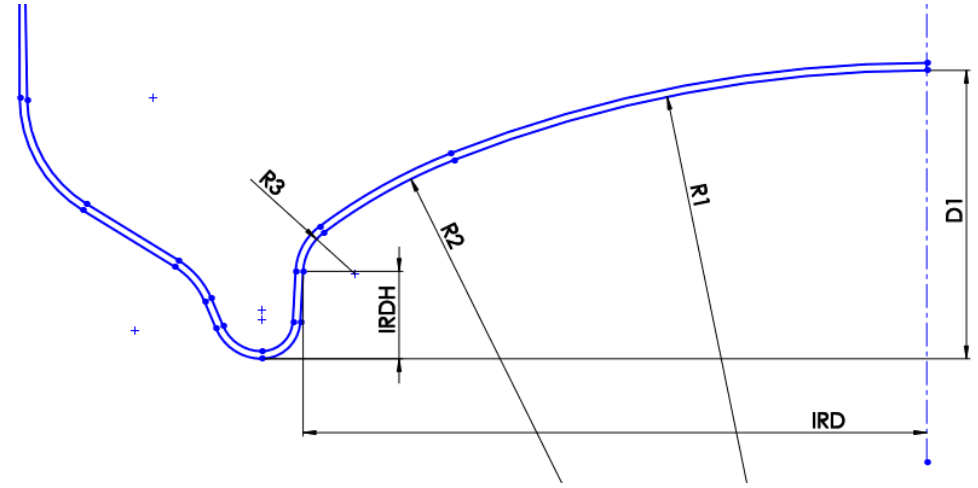

Fig.4: Dome profile with the most important elements of its geometry

When it comes to mechanical properties, the most important parameters are: depth of a bottom (D1) and radii which form the profile of a bottom (R1, R2, R3). The bottom profiles are represented by designs of dies which form the bottom, these are: "173" and "006". Two bottom widths were used in the analysis: 10.50 mm and 11.00 mm. Additional shaping (reforming) is carried out with fixed parameters, i.e. internal reform diameter height IRDH = 2.35 mm and the maximum internal reform diameter IRD = 47.20 mm. The table below shows geometrical dimensions of the dome profiles.

Dome Profile	R1 [mm]	R2 [mm]	R3 [mm]
173	52,10	19,74	1,73
006	52,10	17,43	1,73

Table 1: Geometrical dimensions of the dome profiles

The software used to simulate the domes was eta / Dynaform 5.9.2 with LS-DYNA solver. All settings of processes were set in the options **AUTOSETUP > SHEET FORMING**. To simulate the shape of the bottom, shell-type elements were used. The input was a quarter of a blank of radius R = 79.5mm. The type of material was **36 * MAT_3-PARAMETER_BARLAT**. The charge material, also considered and analyzed in [8] was aluminum alloy 3104 in H19 temper of thicknesses 0.250 mm and 0.241 mm. Properties of the material are listed in table 2.

Property	3104 H19
UTS [MPa]	315
YS [MPa]	284
Elongation [%]	5,44
Young's mod. [GPa]	58
YS/UTS	0,902

Table 2: Properties of material used in simulations [8]

For the numerical analysis, it was necessary to determine the hardening curve and the forming limit curve. For all forming tools (meshed by internal mesher included in Dynaform 5.9.2 software using the "tool mesh" method) shell elements were used and default **`MAT_20 RIGID`** material. During forming, the type of contact between tools was **`*CONTACT_FORMING_ONE_WAY_SURFACE_TO_SURFACE`**, the constant coefficient of static friction μ = 0.08, and the parameter Element Formulation Fully Integrated S/R **`ELFORM = 2`**. The initially assumed experiments with changes in velocity of forming and with different variants of the coefficient of friction were abandoned due to problems with obtaining appropriate bottoms without failure during pressure tests. Fig. 5 presents an example of a bottom geometry after forming a bottom in a horizontal press and after reforming. The changes in shape of a reverse wall are indicated in circles.

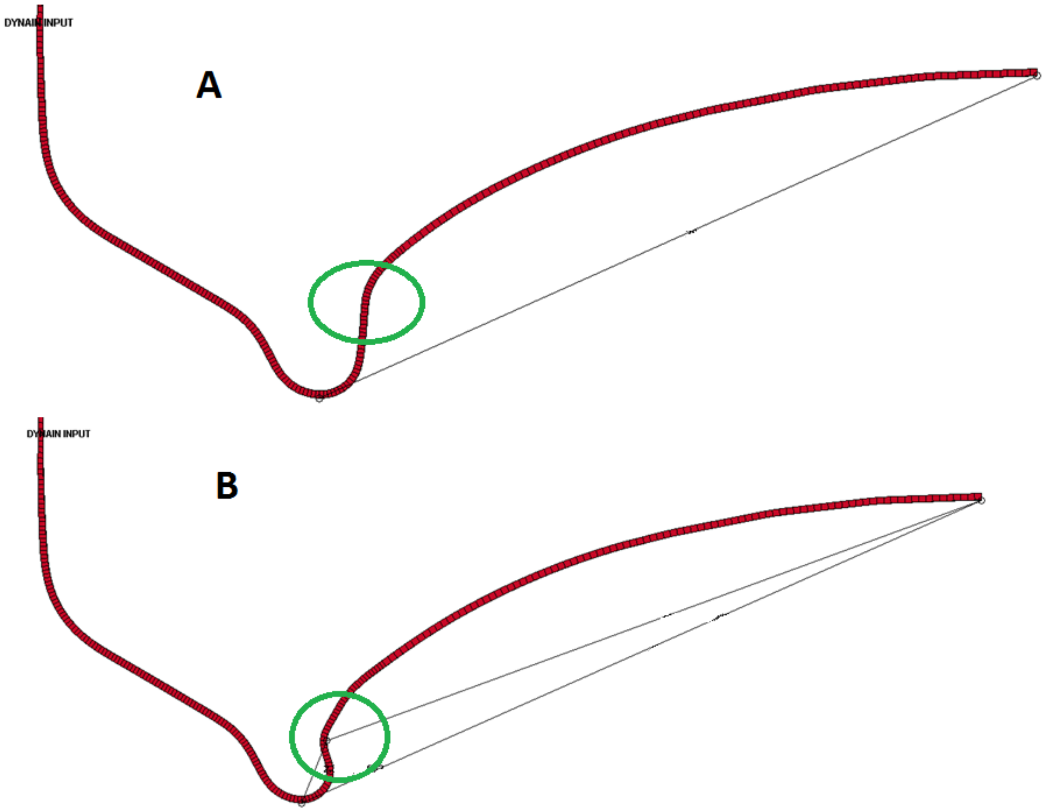

Fig.5: Dome profile after forming (A) and reforming (B)

Fig. 6 presents a list of bottom profiles. The differences in the geometrical dimensions are noticeable.

Fig.6: Geometry of dome profiles

4 Dome Reversal Pressure – Finite Element Analysis

The domes used in simulations of dome reversal pressure test were formed in Eta/Dynaform and included the full history of stresses, deformation and changes in material properties. These analyzes were performed in a special module prepared for testing in an LS-DYNA. The pressure test involves loading an empty can with pressure which is dispensed inside the can. The test is completed when the dome of the can is reversed outside. The can is charged with pressure which increases during the test, as shown in Fig.7.

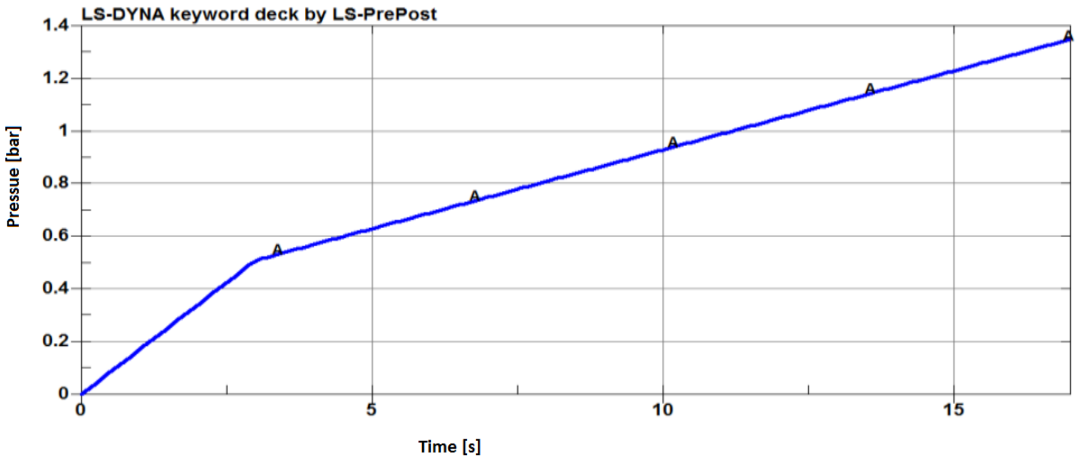

Fig.7: Increase in internal pressure during dome reversal pressure test

The analysis was carried out using the automatic switch of types of analysis - from IMPLICIT to EXPLICIT. Only domes themselves were taken into the analysis as no difference was observed between such analyses and analyses performed on an entire volume of a can. The dome surface was modeled with 2D shell elements. The thickness of walls and residual stresses after drawing were also included in the model. The scheme of boundary conditions for the test is shown in Fig. 8.

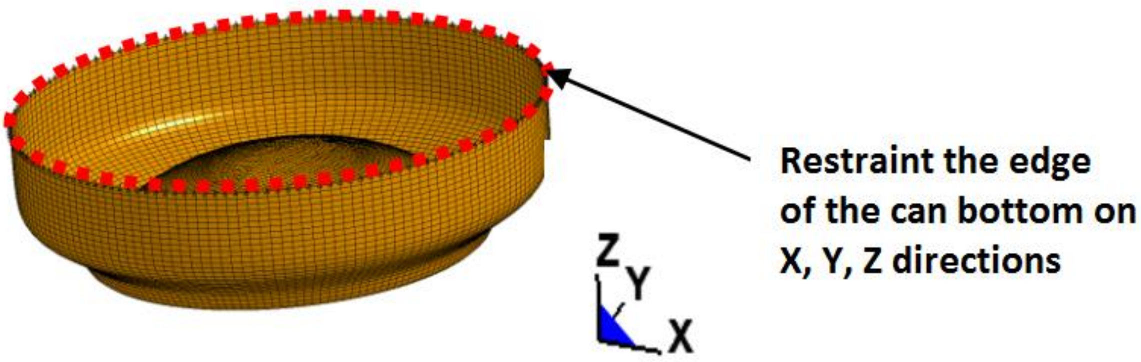

Fig.8: Scheme of the boundary conditions for the test

5 Results

In the numerical analyses, domes of a shape presented in Fig. 6 were obtained. Their geometrical dimensions are presented in Table 3 and in the graph. .

Sample	GAUGE [mm]	Dome Depth [mm]	Dome Profile	DRP FEA[kPa]	DRP ph. test [kPa]
241_1050_006	0,241	10,50	006	596	0
241_1050_173	0,241	10,50	173	700	0
241_1100_006	0,241	11,00	006	615	0
241_1100_173	0,241	11,00	173	780	0
250_1050_006	0,250	10,50	006	618	640
250_1050_173	0,250	10,50	173	740	665
250_1100_006	0,250	11,00	006	635	690
250_1100_173	0,250	11,00	173	813	715

Table 3: Parameters and results of dome reversal pressure test

The data were presented in relation to dome forming as these parameters have the most significant impact on mechanical properties of a bottom. Profiles 006 and 173 profiles differ significantly, especially in the respect of radius R2, which is mainly responsible for the shape of a dome after reforming. This change also causes higher resistance to internal pressure. In the case of 173 profile , the resistance is higher than in 006 profile, due to higher value of R2. Plate thickness does not strongly affect DRP when the same dome profiles are analyzed. As a result, it is possible to use thinner material in production. The depth of a dome has significant impact. For the same profiles, deeper bottom allows to get higher values of dome reversal pressure. What is more, 173 profile is more susceptible to a 0.50 mm change in depth.

There are differences between values obtained in the FEM analysis and values from physical tests (Fig. 9). However, when it comes to behavior and appearance of the dome after tests, the visual effect after numerical analyses was similar to the effect after actual tests. (Fig. 10).

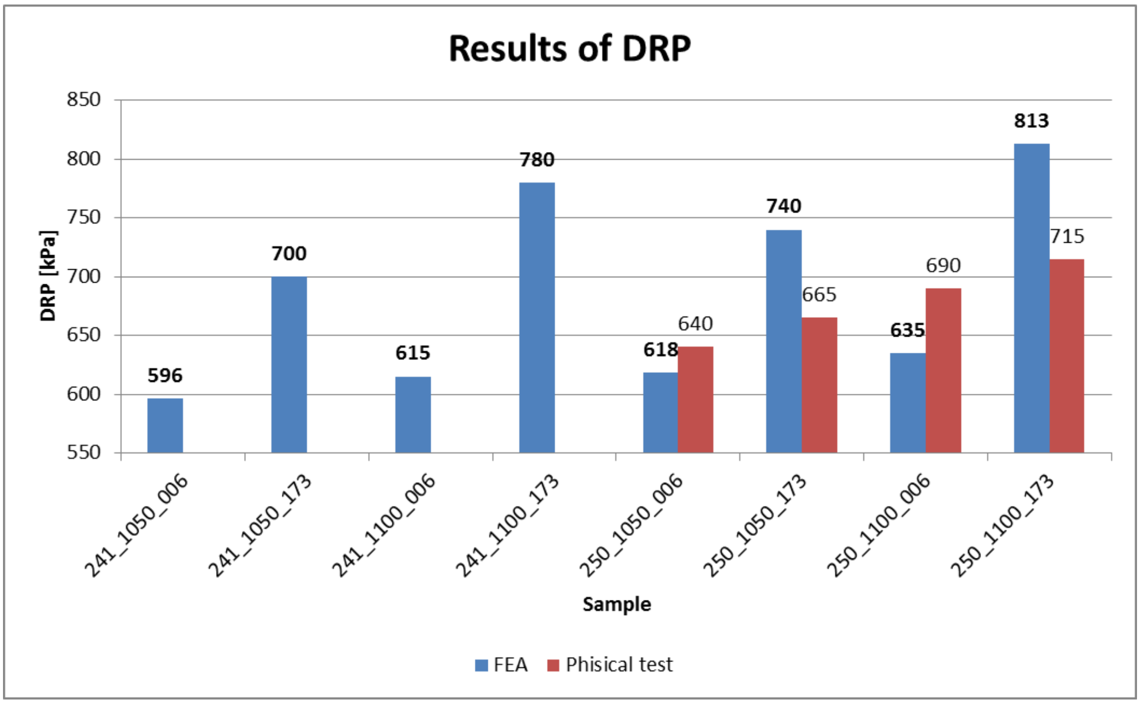

Fig.9: Comparison of results from FEA and from actual dome reversal pressure tests

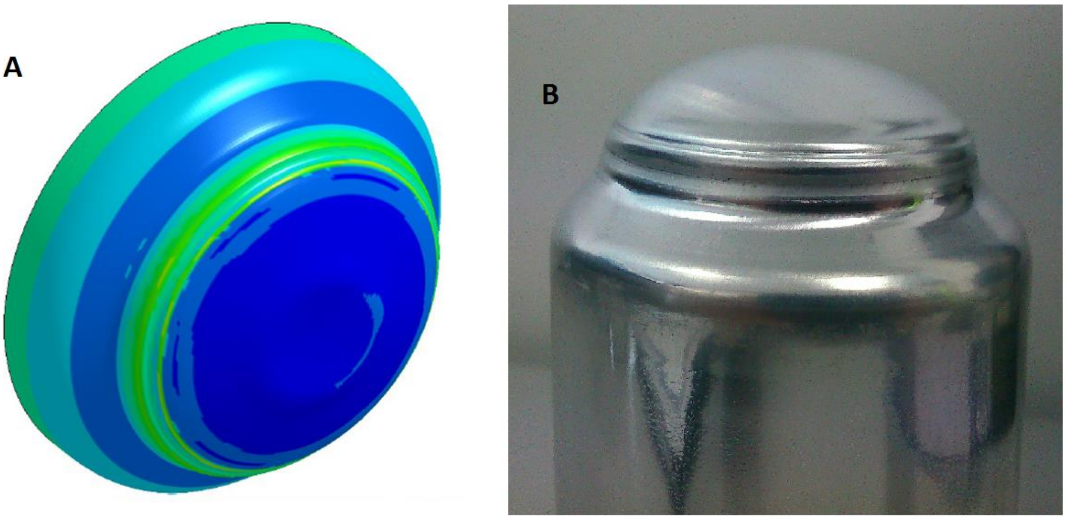

Fig.10: Comparison of numerical and physical appearance of bottom after dome reversal pressure test

6 Conclusions

The results of numerical analyses are promising, especially when compared to physical tests. However, the model for the analysis of dome reversal pressure needs further optimization of both the simulation time and obtained results (in relation to physical tests).

The numerical analysis showed that the depth of a bottom influences its resistance to internal pressure, which is consistent to actual tests. The change in the depth of a bottom of 0.50 mm results in higher resistance to internal pressure of beverage cans.

In the numerical analysis of two bottom profiles which differed only in the value of R2, a big difference in results of DRP was obtained, although, in real physical tests the difference was much less visible.

Radius R2 is a significant parameter that determines final shape of a bottom after reforming and thus influences its mechanical parameters.

The next step in the numerical analysis of modeling of dome reversal pressure tests is optimization of the model to assure its coherence with physical tests as well as optimization of time needed for simulations. In the case of can bottoms, future actions will be focused on broader range of depths and further attempts of numerical analyses with changing such parameters as: velocity of forming and the coefficient of friction.

7 Acknowledgement

The publication is based on research carried out within a framework of national program INNOTECH, supervised by the National Centre for Research and Development, In-Tech program.

The research development project entitled: "Development and implementation of a comprehensive material-saving production technology of aluminum beverage cans", carried out on the basis of financing agreement no. INNOTECH-K2 / IN2 / 26/182070 / NCBR / 13 from May 9, 2013.

8 References

[1] Dick R.E.: “Improvements to the beverage can redraw process using LSDYNA”, 7th International LS-DYNA Users Conference (2002), Session 15 – Metal Forming Technology.

[2] Danckert J.:”LS-DYNA used to analyze the manufacturing of thin walled cans”, 6th European LS-DYNA Users’ Conference (2007).

[3] Dick R.E., Yoon J.W.: ”Effect of Material Characteristics on Wrinkling During Dome Forming of a Beverage Can using LS-DYNA”, 10th International LS-DYNA Users Conference (2008), Session 17 – Metal Forming.

[4] Jordan-Cordera A., Miranda-Valenzuela J.C: “ Simulation and Analysis of Beverage Can Necking Process Using LS-DYNA“, 8th International LS-DYNA Users Conference (2004), Session 9 – Metal Forming Technology.

[5] Bielenberg R.W., Magner S.H., Reid J.H.: “Sidewall Indentation and Buckling of Deformed Aluminum Beverage Cans”, 6th International LS-DYNA Users Conference (2000), Session 10 – Impact 2.

[6] Conn B.A., Anugonda P., Reid J.D.: “Piercing of Aluminum Beverage Cans”, 6th International LS-DYNA Users Conference (2000), Session 10 – Impact 2.

[7] Utsunomiya H., Nishimura H.: “Effect of base profile of a DI beverage can and material properties on the dome reversal pressure”, Journal of materials processing technology, Vol 97 (2000), pp. 54-60.

[8] Rękas A., Latos T., Budzyn R., Fijałkowski M., Brodawka Ł.: “The analysis of influence of sheet properties on the ironing process of thin-walled cylindrical shell products from aluminum alloys”, Key Engineering Materials, Vol 641, April 2015, pp. 232-245.