

Application of shell elements in simulation of cans ironing

A V Andrianov¹, Y A Erisov², E V Aryshensky² and V Y Aryshensky¹

¹ ZAO “Alcoa SMZ”, Alma-Atinskaya Str., 29, Samara, 443051, Russia

² Samara National Research University, Moskovskoye Roadway, 34, Samara, 443086

E-mail: Aleksey.Andrianov@arconic.com

Abstract. In the present study, the special shell finite elements are used to simulate the drawing with high ironing ratio of aluminum beverage cans. These elements are implemented in commercial software complex PAM-STAMP 2G by means of T.T.S. normal stress option, which is used for ironing to describe well normal stress. By comparison of simulation and experimental data, it is shown that shell elements with T.T.S. option are capable to provide accurate simulation of deep drawing and ironing. The error of can thickness and height computation agrees with the engineering computation accuracy.

1. Introduction

Beverage aluminum cans production is widely spread throughout the world. Deep drawing with ironing is the key process for such thin wall cans production [1]. Such process research and analysis are the focus of multiple studies [2-9]. They demonstrate that major problems, arising during can production (ears, wrinkles, thickness variability, fracture, etc.), are associated with the unstable ironing process, defined both by the process parameters (tool geometry, friction coefficient, blank-holder force, etc.) and blank material properties. Such a wide variety of different factors makes immediate production problems solution, using “trial and error” method as the most commonly applied in production practice, very expensive and slow.

This is why the role of the finite element modeling grows up, enabling significant amount of studies translation into the field of numerical experiment, comprehensive process investigation, a large number of the alternative options review. The specific feature of sheet metal forming processes simulation is application of shell finite elements, enabling computation time reduction while maintaining the accuracy [10]. However, conventional shell elements do not provide the required accuracy during normal stress calculation (i.e., thickness stress), which presents the mandatory condition in the simulation of the ironing process. This is why major studies, discussing the beverage cans production process, either look into axisymmetric, i.e. two-dimensional task [11-14], or apply solid finite elements [13, 15-19]. However, two-dimensional task statement cannot address the important factor of in-plane properties anisotropy. In both cases to achieve accurate and valid simulation results, minimum three finite elements shall represent the blank thickness, which is especially critical for solid elements, as their number increases dramatically. Therefore, the computation time increases significantly, thus rejecting immediacy as the major simulation advantage.

An alternative approach consists in using finite elements with special properties. For example, shell elements, possessing solid elements properties. Such elements are supported by commercial software complex PAM-STAMP 2G, which implements special through thickness stress (T.T.S.) shell elements

option. Such function improves normal stress computation accuracy and is recommended for ironing simulation [20]. At the same time it preserves the major benefit of shell finite elements, that is quickness of computation.

In this connection, the purpose of the present study is to assess the potential of T.T.S. shells application for simulation of drawing with a high ironing ratio, using aluminum beverage cans forming as an example.

2. Description of the beverage can forming process

Figure 1 shows the geometry of a typical aluminum beverage can, featuring wall thickness variation from the “dome” to the “neck”. Can “thin” and “thick” walls are identified accordingly.

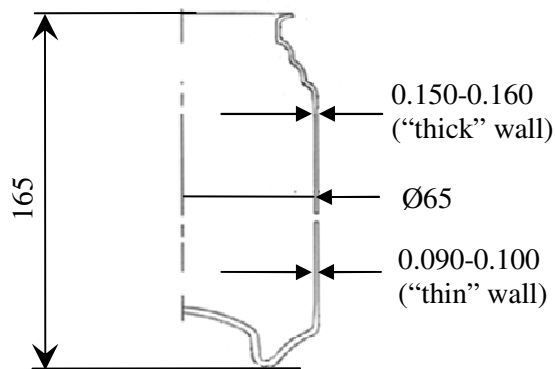


Figure 1. The geometry of a typical 0.5l can (mm).

The can making process consists of several steps. In the initial step, the round blank is cut out and drawn without ironing. Produced cups are fed to the deep drawing tool, where they are redrawn in the first stage and ironed in three consecutive stages with dome forming in the end (figure 2). The specific feature of this step is a very long punch stroke, required to pull the can body through 4 dies. Eg., for a 200 mm high can, the punch stroke reaches 500 mm.

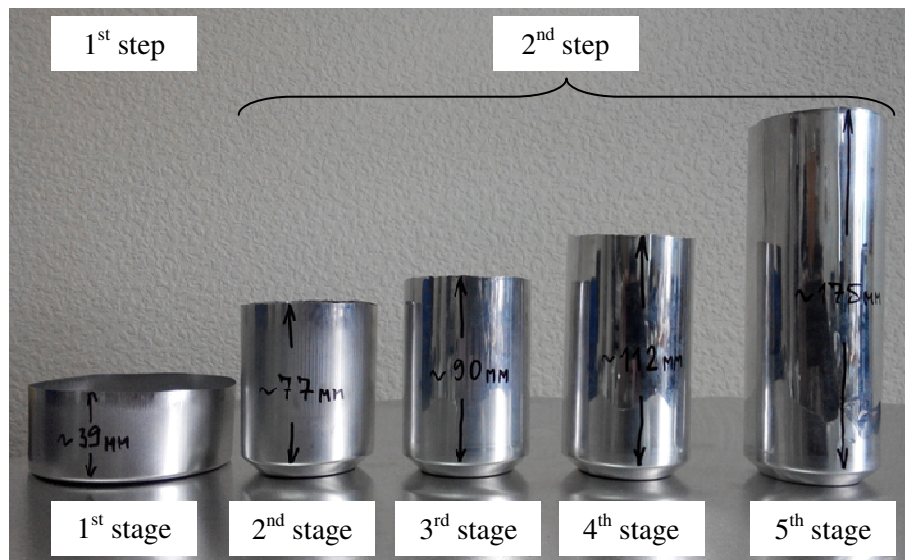


Figure 2. The cans shape after each forming stage.

The wall ironing ratio is strictly pre-determined for each stage. Approximate drawing and ironing ratios for each forming stage are presented in table 1. Thickness variability along the can height is provided by the punch geometry. It shall be also noted, that in the second and third stages the metal stays in two ironing rings at the same time.

Table 1. Drawing and ironing ratios

	1 st step		2 nd step		5 th stage	
	1 st stage	2 nd stage	3 rd stage	4 th stage	“Thin” wall	“Thick” wall
Drawing ratio	0.63	0.65	-	-	-	-
Ironing ratio	-	-	0.86	0.84	0.86	0.53

3. The computer model of the beverage can forming process

For elements number reduction the model was designed for ¼ volume, restricted by coordinate planes ZOX and ZOY (figure 3). The Coulomb friction coefficient was assumed to be 0.06. In the first and the second stages, the constant force, equal to 3 kN, was applied to the blank-holder in the direction of a Z axis. The punch moves with the constant speed of 10 m/s along the Z axis both during the first and the second steps. The tooling (punches, dies, blank-holders and ironing rings) is assumed to be rigid bodies.

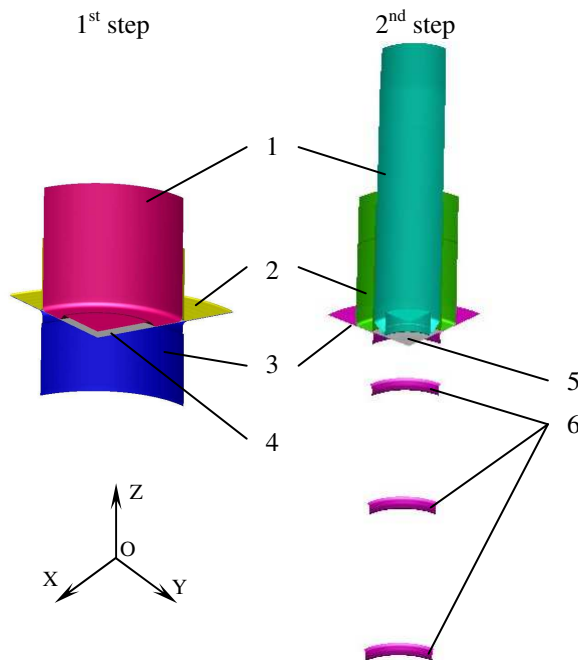


Figure 3. The process model: 1 – punch; 2 – blank-holder; 3 – die; 4 – blank; 5 – cup; 6 – ironing ring.

The specific feature of the developed model is application of 4-noded shell finite elements with T.T.S. option, having 5 integration points through the blank thickness. The blank diameter is 160 mm, thickness S is 250 μm . Blank material is aluminum alloy 3104. An orthotropic elastic-plastic material model (Hill48 model) was used for material behavior description. Rolling direction coincides with an X axis. Material strain hardening during plastic deformation followed Swift law:

$$\sigma_{eq} = k \left(\varepsilon_0 + \varepsilon_{eq} \right)^n,$$

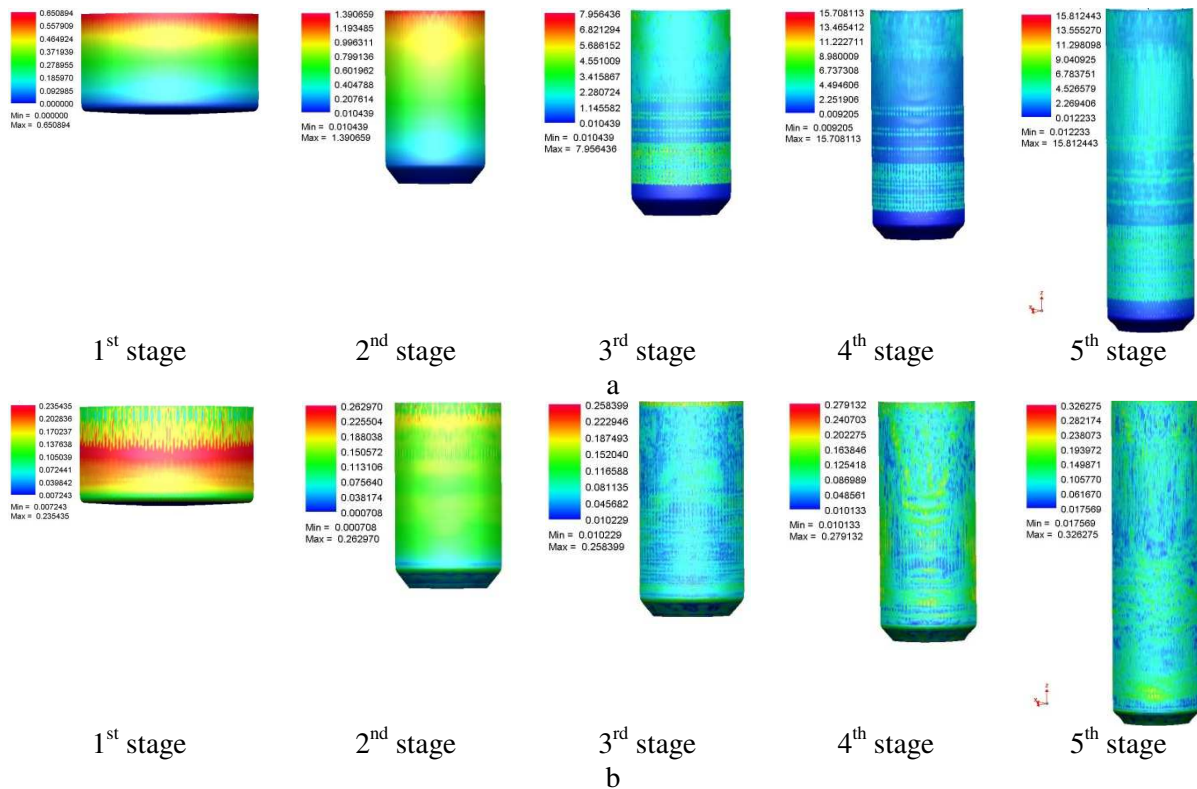
where σ_{eq} and ε_{eq} are equivalent stress and strain; ε_0 is plastic flow initiation strain; n and k are strain hardening exponent and coefficient. The properties of aluminum alloy 3104 are specified in table 2.

4. Simulation results and computer model verification

Simulation results, represented by equivalent stress (GPa) and strain distribution, are shown in figure 4.

Table 2. The properties of aluminum alloy 3104

Parameter	Value
Young's modulus, E (GPa)	69.0
Poisson's ratio, ν	0.34
Density, ρ (kg/m ³)	2.71
Anisotropy coefficients	
R_0	0.964
R_{45}	1.057
R_{90}	0.996
Strain hardening coefficient, k (GPa)	0.387
Strain hardening exponent, n	0.066
Plastic flow initiation strain, ε_0	0.0089

**Figure 4.** Distribution of equivalent strain (a) and stress (b) by can forming stages.

For computer model verification, 5 sample cans were obtained for each drawing stage. The wall thickness was measured by the digital micrometer (2 μm accuracy), along the samples generatrix. The measurements were taken in the rolling direction only (every 5 mm, 3 measurements in each point). The obtained results were averaged. After that the actual wall thickness from cup to can were compared with the computer model based calculations. Thickness distribution along generatrix of can for all forming stages is plotted in the figure 5.

Absolute and relative errors were calculated at each point for the model validation. Deviation of simulation results from the actual product thickness is listed in table 3. As seen from the presented data, the maximum relative error is observed in the 5th stage and is equal to 8.04%, which is allowable for engineering calculations.

In addition, the model verification was performed through correlation of the actual can height with simulation results. The measurements were taken with a digital caliper (10 μm accuracy). The measurements were taken at 3 points, obtained results were averaged. Height prediction error is listed in table 4. The maximum deviation is observed in the second stage.

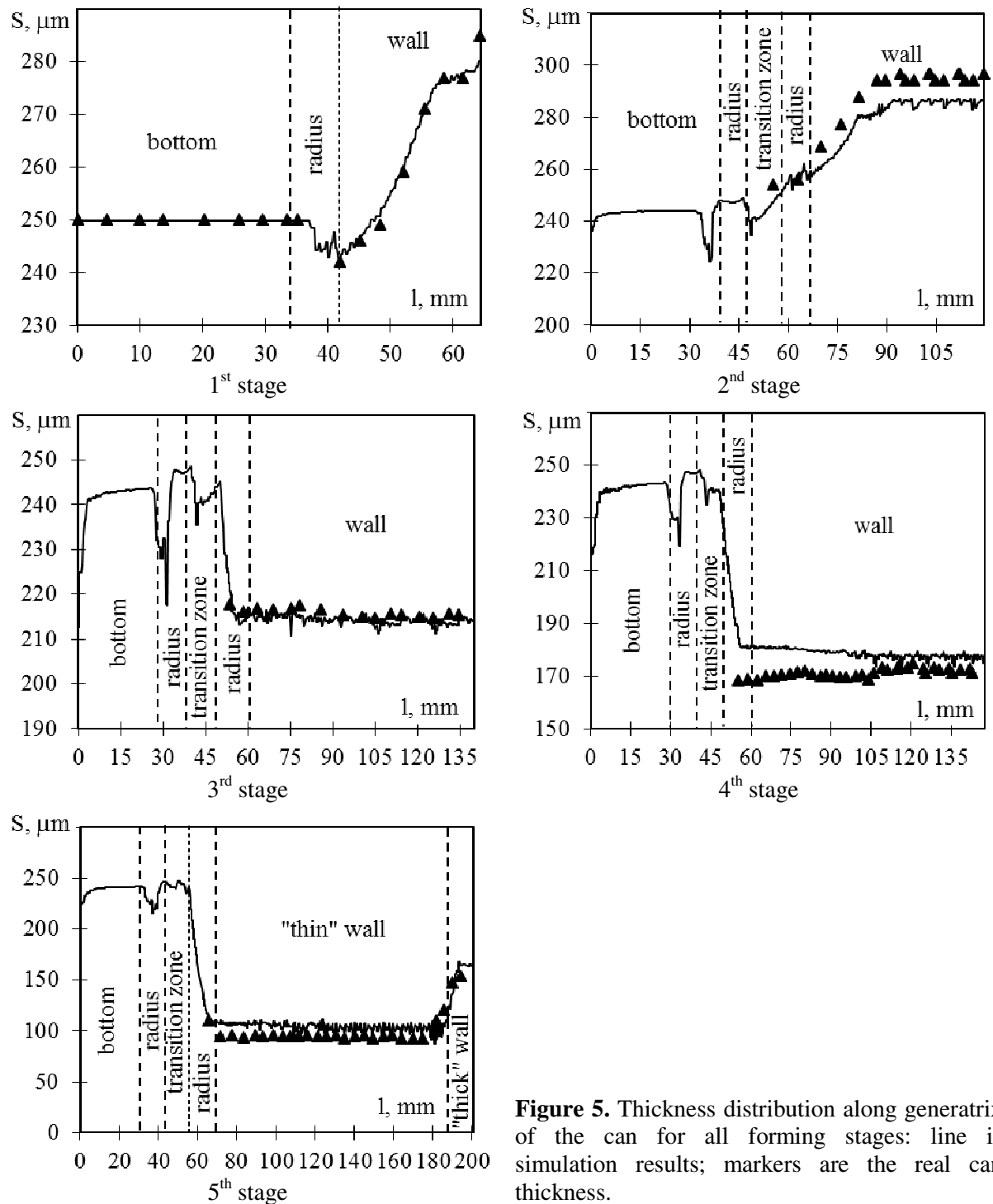


Figure 5. Thickness distribution along generatrix of the can for all forming stages: line is simulation results; markers are the real can thickness.

Table 3. Thickness prediction error

Stage	Wall thickness, μm		Absolute error, μm	Relative error, %
	Simulation	Experiment		
1	242.1-280.1	242.0-287.0	0.1-6.9	0.02-2.42
2	231.3-286.8	240.2-298.8	0.1-13.3	0.02-5.42
3	210.8-222.4	214.8-217.8	1.1-4.6	0.51-2.75
4	177.5-181.8	168.6-173.4	4.8-12.8	2.80-7.58
5 ("thin" wall)	89.9-104.4	93.1-107.7	0.1-8.0	0.08-8.04
5 ("thick" wall)	155.6-161.7	149.9-152.5	8.1-11.8	5.03-7.66

Table 4. Height prediction error

Stage	Can height, mm		Absolute error, mm	Relative error, %
	Simulation	Experiment		
1	38.51	38.99	0.48	1.24
2	73.04	76.19	3.15	4.31
3	89.32	90.02	0.7	0.78
4	111.00	111.02	0.02	0.02
5	173.57	174.8	1.23	0.7

5. Conclusion

1) Computer model based computations analysis shows that all drawing and ironing stages from the cup to the finished can are fully compatible with the actual samples, and the model can be applied for deep drawing process description during aluminum can production.

2) Can thickness and height measurements error agrees with the engineering computation accuracy and is, probably, associated with the following factors: the difference between the preset friction coefficient and actual boundary conditions, differences between the mechanical properties of the simulated workpiece and the real sheet.

3) Simulation and experimental data correlation demonstrated, that shell elements, possessing the T.T.S. option, are capable to provide accurate simulation of deep drawing and ironing and can be applied instead of solid elements even at high normal stress values.

4) In the future, the designed computer model can be applied for the analysis of can fractures during can making.

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