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INVESTIGATION ON THE BUCKLING OF AEROSOL CANS DURING THE BOTTOM FORMING PROCESS

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Abstract: In this paper, the mechanical analysis of the bottom forming process of aluminium aerosol cans is presented. Our main objective is to investigate the buckling of the shaping process. The commercial finite element software Abaqus is used to solve the problem. The can geometry is mapped by thin three-dimensional shell element. The problem is highly nonlinear, Riks and displacement based methods are used to trace the equilibrium path and calculate the reaction force - displacement diagram with the buckling load, at which the loss of stability occurs. The effect of different features of the can geometry is investigated on the buckling load, such as the fillet radii of the bottom of the can, the thickness of the shell. We included the effects of the imperfections in the geometry, the mesh and the friction between the tool and the can.

Keywords: Aerosol cans, bottom forming, shells, FEM, Abaqus, buckling

INTRODUCTION

In recent years aerosol cans craft from aluminium are reporting mounting growth rates all over the world. Aerosol cans may also be made from a process known as extrusion or impact extrusion using 99.5 % pure aluminium sheet or in some cases steel. In an impact extrusion process, a hydraulic ram punches an aluminum slug to begin forming the can, which creates the initial geometry for the further forming steps. The first phase of the forming process of aerosol cans is the bottom forming process which is the topic of this paper.

It is well-known, that the behavior of thin shells is highly nonlinear. There are several textbooks devoted to the mechanics and finite element modelling of thin shell structures, such as [1], [2] or [3]. Patten [4], Hardy and Abdusslam [5] investigated the back extrusion of cans. Belblidia et. al. [6], [7] developed finite element techniques to determine the stress state and burst pressure of thin aerosol cans. Paper [8] investigated various technological parameters of the forming process using experimental data, while Takeutshi [9] presented a few basic problems in the forming process of aerosol aluminum cans. Several works [11-15] deal with the mechanical and experimental analysis of the necking process (reaction forces) for thin shells and the buckling limit with the determination of the crushing force during these last shaping steps.

In this study, the main objective is to investigate the forming process of the bottom part, in which a spherical or conical surface is created. These features are important, because these help the cans to withstand the internal pressure coming from different filling media and strengthen the can (increase burst pressure), furthermore these ensure the stable standing of the cans. The efficiency of the finite element method and Abaqus is presented for the design process and analysis of thin-walled cans.

AIMS AND DATA

The forming process of thin shell structures is a highly nonlinear problem, which involves geometric and material nonlinearities with contact equations. It is a large deformation problem, in which the material is a strain hardened aluminium Al99.5 (EN AW 1050). Our aim is to calculate the reaction force – displacement diagram, then to determine the crushing force, which is the reaction force, at which the loss of stability occurs. Different aspects of the forming technology are going to be analysed. The effect of the geometry of different features of the aerosol cans is investigated on the reaction forces and on the crushing forces.

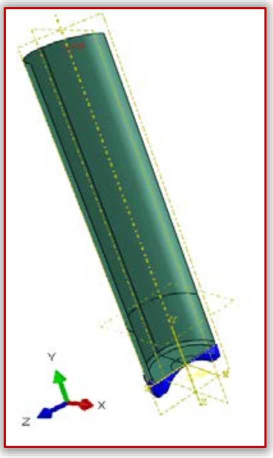

Figure 1. The sketch of the geometry

According to experiments, the Young modulus of the aluminium is 75 GPa, the Poisson's ratio is 0.4, the yield stress is 120 MPa and a bilinear plasticity law is used with 230 MPa stress at φ=4 plastic strain level. The friction coefficient between the can and the steel tool is 0.05. The initial geometry of the can and the tool can be seen in Figure 1. The diameter of the can is 44 mm, the length of the can is 200 mm, the wall thickness of the bottom part (base of the cylinder) is 0.9 mm, the thickness of the mantle of the cylinder is 0.36 mm. The piece is constrained at its side of 35 mm height against radial motion. The radius of the steel tool is 20.2 mm.

MODELLING TECHNIQUE

Due to the nature of buckling, three-dimensional geometry with shell elements is used to solve the problem. The aluminium piece is considered a solid body (elasto-plastic shell), while the steel tool is modeled as a discrete rigid part. One of the main sources of the numerical difficulties comes from the contact equations between the can and the tool, so linear elements are used to create the mesh of the can. This cylinder is constrained at its side against radial motion, while there is a kinematic coupling at the top edge of the shell using a reference point (Figure 1 - RP) as a control point to pin the nodes there. Another reference point controls the motion and position of the rigid tool.

To include the effect of the imperfections, a linear perturbation/frequency analysis was carried out. Then the eigenshapes are determined and mapped to the initial geometry using different scale factor. According to measurements, this scale factor is around one tenth of the shell thickness, so we used the value 0.04.

To crush the can, a prescribed displacement is applied at the reference point of the rigid tool in the direction *y*.

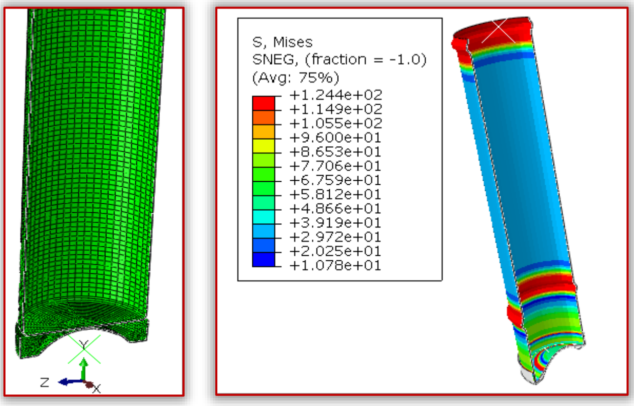

Figure 2. The mesh of the problem and the deformed state of the ideal geometry with the von Mises stress distribution (in MPa)

At first, the effect of the mesh is investigated on the ideal geometry during Static/general and Riks methods. Linear and quadratic element were used with different mesh densities. The latter led to significantly increased solution time, while the results were approximately the same, the crushing force (that belonged to the element size 2 mm) was 5928 N. The crushing force coming from linear elements with the average size of 2 mm was 5927 N, while with the element size of 1 mm the loss of stability occurred at 5924 N. The chosen mesh with linear elements (average size 2 mm) can be seen is Figure 2. To facilitate the contact calculations and to improve the accuracy, a finer mesh was created at the contact region and at the radius of the base of the cylinder.

A diverse combination of the eigenshapes can be used and multiple disturbed geometries can be mapped within a specified tolerance range. During experiments, the can deformed above the radially constrained side area. The eigenshapes of Figure 3 were applied to the ideal geometry, the result can be seen is Figure 4.

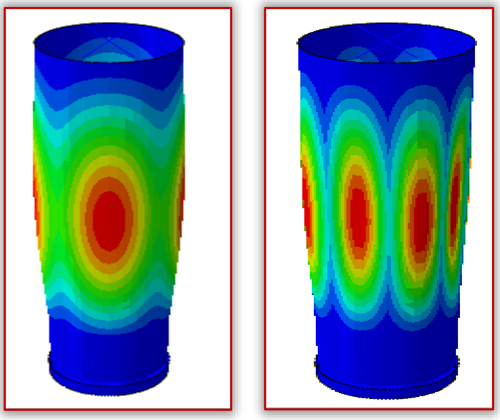

Figure 3. Some of the eigenshapes of the can

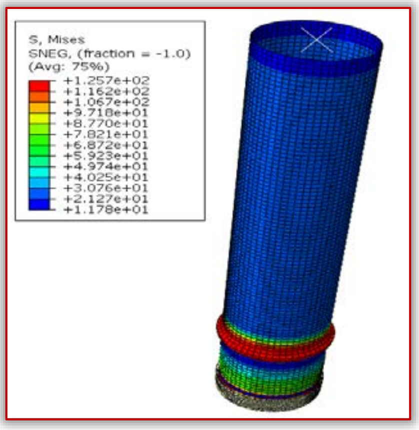

Figure 4. The deformed state of the disturbed geometry

In this case the maximum reaction force was 5910 N, which is in good agreement with the experimental results. We are going to use these imperfections for our further investigations.

THE EFFECT OF THE GEOMETRY OF THE CAN

There are multiple features that affect the shaping forces and may affect the buckling load. At first, let us investigate the effect of the fillet radius at the base of the can. Consider three different radii: 0.7 mm, 2 mm and 4 mm. The reaction force – displacement curves can be seen in Figure 5. The results show, that the maximum reaction forces are the same, but the force requirements of different deformations differ.

In the next step, the effect of the shell thickness at the base of the cylinder is investigated. Seven different values are considered: 0.36 mm, 0.6 mm, 0.8 mm, the original 0.9 mm, 1 mm, 1.2 mm and 1.7 mm. Figure 6 shows the results. Here we can see, that at a certain value, the crushing forces are the same, but when the thickness of the base is greater, than this value (in our case it is approximately 1.05 mm), the buckling load decreases. It is clear, that with the increase of the base thickness the reaction forces increase too.

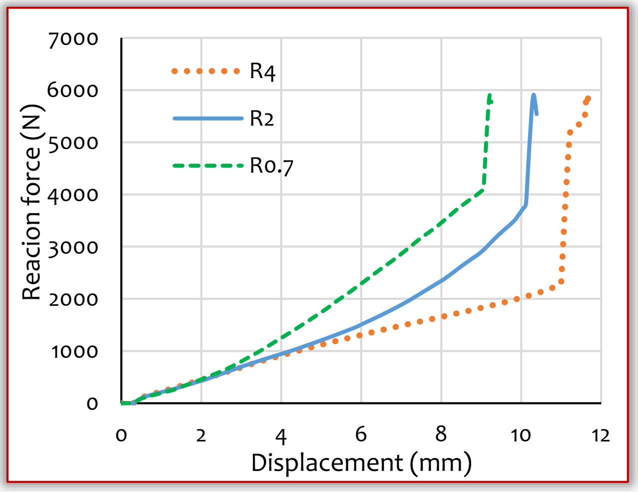

Figure 5. The reaction force – displacement diagrams for different fillets between the base and the side of the cylinder

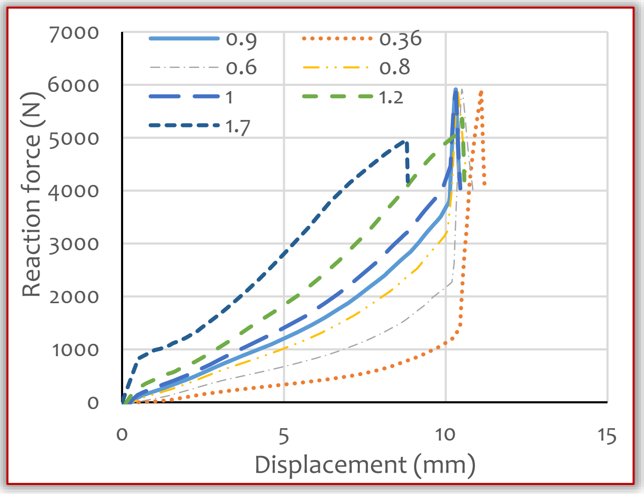

Figure 6. The effect of the shell thickness at the base of the cylinder.

In the following case, the thickness of the base is constant (0.9 mm), the thickness of the side of the cylinder changes. The investigated values and the results for the loss of stability are shown in Figure 7. It is clear, that the reaction forces are similar at a significant range of the thickness values, but the buckling loads differ. Here we note, that the software had some numerical issues with smaller values, especially below 0.22 mm and canceled the simulation with an error. Furthermore with these diagrams, we can determine the limits of the geometry, because we get the maximum deformation (until the buckling) for different values, and then these can be paired up with the appropriate factor of safety. In our current example, the maximum displacement of the can with 0.22 mm side thickness is 9.7 mm (excluding the effect of springback, which can be easily calculated by adding an extra deload step in our model).

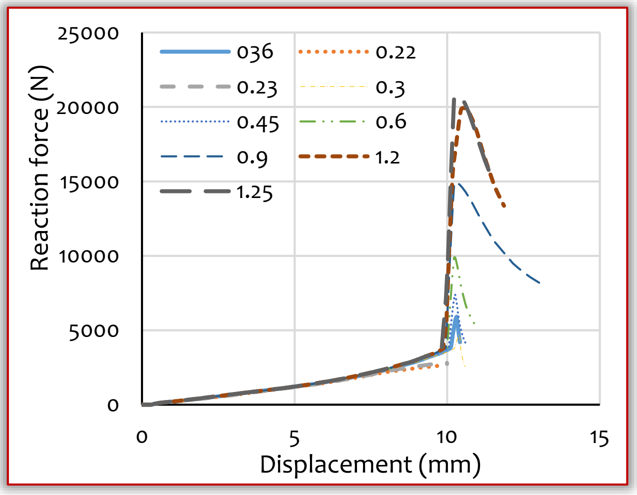

Figure 7. The effect of the thickness of the side on the reaction forces.

THE EFFECT OF GEOMETRY OF THE TOOL AND FRICTION

Let us consider the original can geometry with different tool radii. Figure 8 shows the reaction force – displacement curves for different values. The crushing forces are approximately the same, but the reaction forces during the forming process increase with the increase of the tool radii. To take into account the springback effect, 8.25 mm axial displacement is required to form an 8 mm deep spherical feature. To achieve this, the following reaction forces are required: 14 mm – 2101 N; 16 mm – 2230 N; 18.5 mm – 2375 N; 20.2 mm – 2480 N; 23 mm – 2640 N; 26 mm – 2810 N.

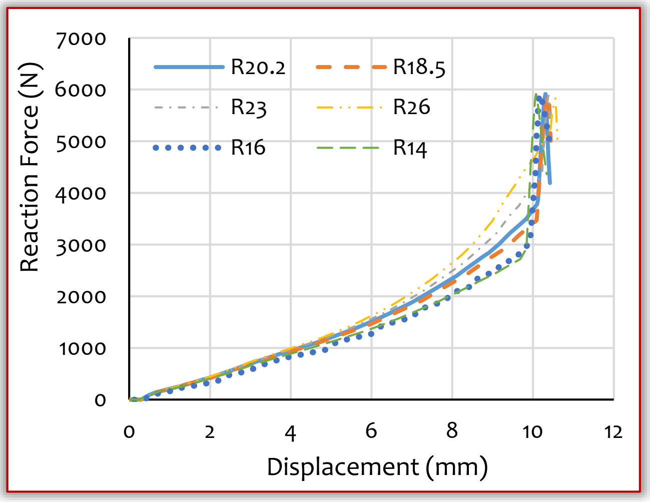

Figure 8. The effect of the radius of the tool on the reaction forces

Finally, the effect of the friction coefficient between the tool and the can is investigated on the reaction forces. Six different values were considered, the results can be seen in Figure 9. I turned out, that the friction coefficient do not significantly affects the reaction forces in this case.

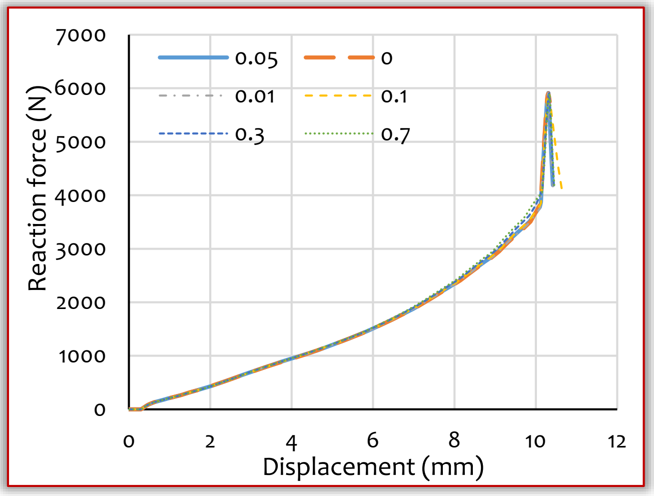

Figure 9. The effect of the friction coefficient

CONCLUSIONS

This paper presents a numerical method to determine the reaction forces during the bottom forming step of thin aerosol cans with the commercial finite element software Abaqus. The three-dimensional geometry was mapped by shell elements introducing imperfections and nonlinearities. It is important to investigate the loss of stability to reduce the number of waste products and to make the mass production more efficient. Multiple features of the geometry were investigated. We could outline the features, that significantly influence the reaction forces required to form the can, thus can be used in the design process to determine the limits of the geometry when compared to the crushing forces. The main contributing factors were the shell thickness of the base of the cylinder, then the different radii in the geometry. An efficient method is presented to calculate the crushing force of the can, at which the loss of stability occurs. The main factor that influenced the stability of the can was the thickness of the side of the can. We found, that the effect of the imperfections on the reaction forces is rather small in this case, although it is necessary to investigate further cases, geometries and parameters, because if the least favorable values occur at the same time for multiple parameters, the buckling load can be significantly lower.

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