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THE EFFECT OF VARIOUS IMPERFECTIONS ON THE BUCKLING OF AN AEROSOL CAN

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Abstract: In this article, the effect of small errors or changes in various parameters (material, geometry, tool angle) on the load bearing abilities of an aluminium aerosol can is investigated. The commercial finite element software Abaqus is used with the Static, Riks step to trace the equilibrium path in order to find the buckling load. Nonlinearities are included in the model. The geometry is mapped by thin shell elements. It is found that although the effect of one imperfection is, in general, not relevant, if multiple of these occur at the same time, the combined potential effect can become significant in a negative way. At the same time, the potential positive effect is less than a half of this.
Keywords: shell, buckling, aerosol can, Abaqus, imperfection

INTRODUCTION

It is well-known that the behaviour of shells is strongly nonlinear. There are many studies devoted to their buckling behaviour. Articles [1-7] detail the effect of various circumstances. One of these effects is the presence of geometrical errors: a significant fluctuation can be experienced in the experimental buckling loads because of very small and diverse geometrical errors.

As for thin-walled cans, because of the nonlinearities and the wide range of possible shapes, it is not possible to establish analytical models for the stability investigations. At the same time, numerical studies are available in the literature. Articles [8,9] focus on the stability of axially loaded aluminium (beverage) cans, with emphasis on the effect of initial geometrical imperfections. Scientific works [10,11] aim to predict the burst pressure level using commercial finite element software. As for the production process of aluminium cans, there are also available sources [12-15]. These later ones focus on one major step during the whole process (like blank drawing, or redrawing the cup).

During the plastic forming process of aerosol cans, the desired final geometry is always reached within a bunch of steps because if too much plastic deformation is applied in one step, buckling (pan) happens resulting in waste product. At the same time, if the number of shoulder shaping steps could be reduced or minimized, it would mean more efficient (faster) production process. Thus, there is a continuous demand to use the reserves in the material more and more efficiently. With the available commercial software packages, it is nowadays absolutely possible to support such efforts.

In this article, focus is put on one intermediate shoulder forming step. The effect of various parameters on this step is investigated numerically by means of commercial finite element computations. After the introduction, the initial data and the solution method are discussed. These sections are followed by the numerical results, conclusions and references.

DATA AND SOLUTION METHOD

The initial (perfect) geometry of the investigated aerosol can is shown in Figure 1 with the so-called related reference values being listed hereinafter. The material is aluminium, modelled with linearly elastic and linearly hardening characteristic. The Young modulus is *73* GPa, the Poisson number is *0.4* with the yield stress being *0.17* GPa. The wall-thickness is constant *0.45* mm. The piece is constrained at its bottom against vertical displacement and, at its side of 42 mm height, against radial motion – as if the can was placed in a sleeve. There is a prescribed vertical displacement at the upmost edge of the can to initiate buckling.

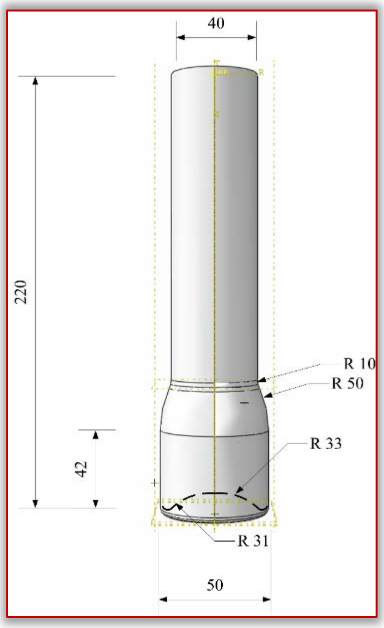

Figure 1. The initial geometry of the can

Numerical simulations are carried out using the commercial finite element software Abaqus 6.13. The can geometry is mapped by its middle surface, using thin shell elements with reduced integration and large-strain formulation. The Static/Riks step with geometrical nonlinearities is selected to trace the primary equilibrium path and thus, to find the limit point corresponding to buckling. First, the load bearing abilities of the reference (or perfect) can is examined. Various small imperfections will then be introduced to the model to evaluate the influence of these perturbation effects. These imperfections are small (<5%) possible errors or changes in the material, geometry and forming tool angle.

In Abaqus, to introduce geometrical imperfections, the eigenshapes of the unloaded can are extracted using the Linear perturbation/Frequency step. Various scaled linear combination of these normalized shapes are then added to the perfect geometry within a possible manufacturing tolerance range to make the can geometry realistic.

To achieve converged and reliable results, simulations with multiple meshes and element types are carried out. The results are gathered in the forthcoming Section.

NUMERICAL RESULTS

First, the typical reference values are selected to get the reference value of the buckling load (if all the circumstances are ideal). As it can be seen from Figure 2, the buckled can shape is then – as expected – axisymmetric. This figure is plotted well after buckling with deformations magnified to be illustrative. Buckling occurs at the location of the radii change. The reference buckling load (reaction force) is $F_{ref}=5.73$ kN. The colour gradient shows the von Mises stress distribution.

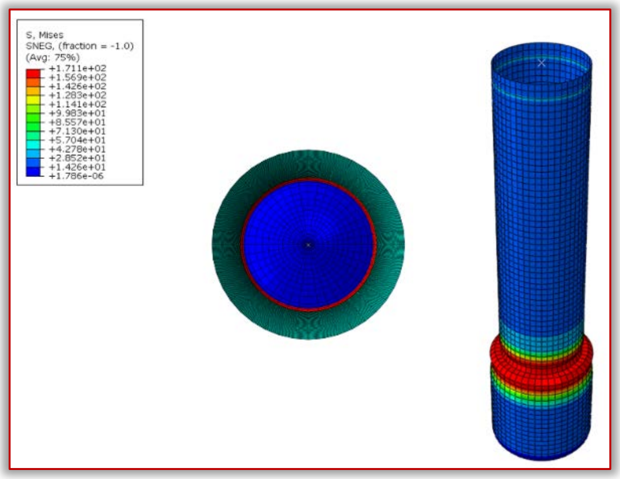

Figure 2. The buckled can shape if all the circumstances are ideal

Next, some of the possible eigenshapes are shown in Figure 3. The maximum displacement for these shapes is unit. It is clear that with diverse combination of such shapes, in essence, multiple disturbed can geometries can be mapped within a specified tolerance range.

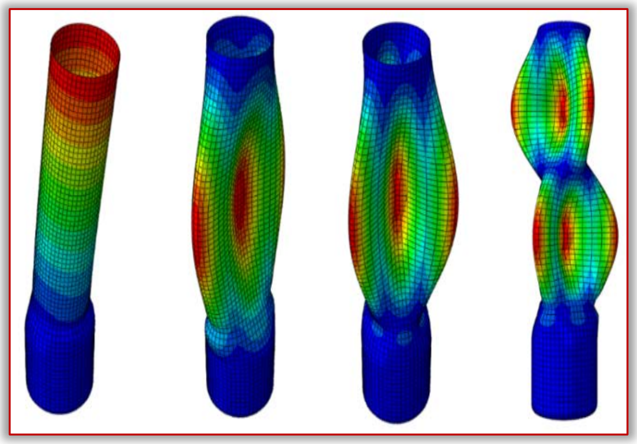

Figure 3. Some of the eigenshapes (magnified displacements)

The effect of various parameters are gathered in the diagrams of Figure 4. Here, $R=F/F_{ref}$ is the quotient of the critical force under imperfections and the reference buckling force. As it can be seen, the wall-thickness (t: ratio of the current and reference thicknesses) has clearly visible influence on R. Greater wall-thickness means greater geometrical stiffness and thus, better load bearing abilities. The plotted points can be approximated by a linear function with a good accuracy despite the nonlinear nature of the problem.

The following diagram presents the effect of the yield stress with all the other parameters left unchanged. It is the only material property having visible influence as a ±5% variation in the Young modulus and Poisson number have no effect at all on the can behaviour. Back to the yield stress, with y denoting the modified yield stress compared to the reference value, the overall effect is a bit less than the effect of the wall-thickness. The change is again linear.

Next, it is demonstrated what happens when the prescribed displacement at the top is not perfectly vertical but there is a small tilt in relation to the vertical axis – like the forming tool was driven askew. Letter a, this time, stands for the angle in degrees with respect to the vertical direction. With this angle, the buckling load decreases quite steeply. At, e.g., 0.5 degrees, R is 0.9 and at 1 degree, the load ratio is just 0.83.

Finally, the shape imperfection is tested with i being the maximum of the initial geometrical shape error in % compared to the wall thickness of the can. Since various eigenshape combinations are selected, the results are not constant but tend to change in a specific range – the upper and lower limits of these ranges are shown by markers in the last diagram of Figure 4. The presence of such imperfection always has negative effect on the buckling load. With i being greater, R is continuously decreasing.

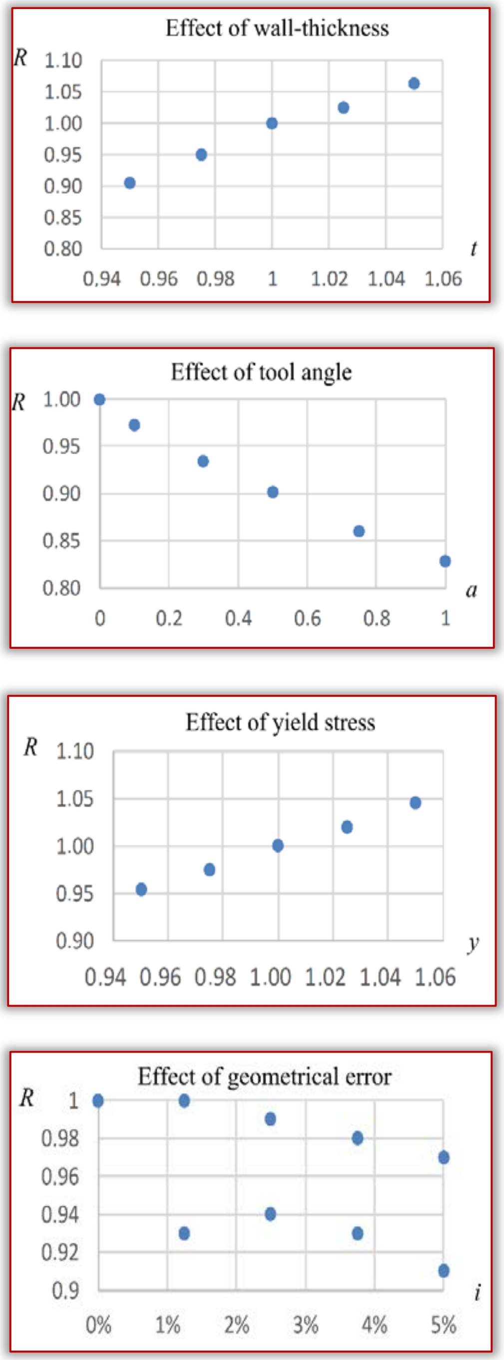

Figure 4.The effect of some properties on the buckling load

With some of these imperfections introduced, not only the buckling load but also the buckled shape changes as demonstrated in Figure 5. Meanwhile buckling still happens at the location of the radii change, the buckled geometries are not axisymmetric anymore and the critical section has polygonal shape.

Based on the above mentioned, it should be found out what happens with the buckling load when the most/least favourable values of these imperfections occur at once. Accordingly, it turns out that, the lowest possible buckling load is *4.11* kN and the greatest one is *6.37* kN. Thus, the ratio *R* can change in the range [*0.73-1.12*] meaning that the potential negative effect of the imperfections is actually more than the double of the possible positive one compared to the reference value.

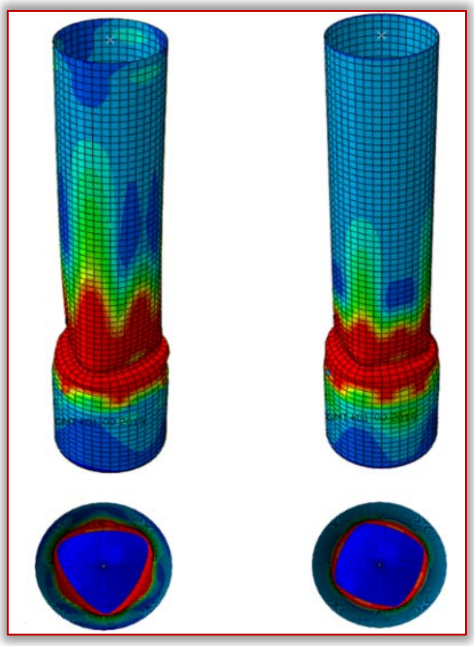

Figure 5. Possible buckled shapes with some imperfections introduced (magnified deformations)

CONCLUSION

The effect of various parameters on the load bearing ability of an aluminium can under plastic forming was investigated numerically with the commercial finite element software Abaqus. The geometry was mapped by 2D thin shell elements with nonlinearities included. It was found that small changes in one parameter have, in general, similarly rather small effects on the buckling load but if the least favourable values occur at the same time for all these parameters, the buckling load becomes significantly lower than for the reference (ideal) model. The potential negative effect is more than the double of the possible positive one. So, surely, the accuracy of the typical parameters are essential for two reasons. First, to reduce the number of waste product and second, because then it is possible to reduce the number of required forming steps to achieve the final shape of the can. Thus, the total forming time can be reduced so the mass production can become more effective.

It is also noted that it is necessary to investigate other geometries to reveal the effect of further parameters, like the radii and typical lengths. Furthermore, handling the issue as a contact problem could also make it more reliable.

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