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Simulation based aerosol can design under pressure and buckling loads and comparison with experimental trials

F. Belblidia [a,*], T.N. Croft [a], S.J. Hardy [a], V. Shakespeare [b], R. Chambers [b]

[a] College of Engineering, Swansea University, Swansea SA2 8PP, UK
[b] Unilever – Aerosols Centre of Expertise, Coal Rd., Seacroft, Leeds LS14 2AR, UK

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ABSTRACT

The present paper focuses on the methodology to simulate an aerosol can when subject to internal pressure and top compressive loadings. Non-linear numerical analysis seeks to predict the level of pop-up and burst pressure levels as the can is subjected to increased pressure loading, along with the determination to top load force causing can wall buckling. These predictions are necessary to access the conformity of the can design to the European Packaging Standard. Numerical findings are assessed against experimental trials for reliability of such a simulation based approach for can design. The challenge of the present study is the use of in situ data to mimic the can predictive behaviour within the Ansys Software suite. This data includes the can material, which is non-linear strain hardening aluminium allowing for yielding at high strain, can wall variable thickness and loading characteristics. The paper highlights some of the modelling issues associated with such analyses and provides some guidance to improve the aerosol can design. The methodology will be used, in a following study, in reducing the can weight by optimal distribution of the can wall thickness whilst revealing an innovative design that fulfils the qualification needs. This will have a direct impact on the material cost, in addition to cost of transport and energy.

1. Introduction

Aluminium is usually sought for its unique properties, mainly low weight and high strength, formability, recyclability, corrosion resistance, and good conductivity of heat and electricity. Aluminium is easily and economically recycled, with energy saving of 95% in the production of recycled aluminium compared to the production of the same quantity of virgin material. In addition, the environmental impact during the material whole lifecycle indicates that 1 g of aluminium used in the industry save about 15 to 20 g of CO_2. Moreover, it is estimated the that 75% of all aluminium produced since the late 19th century is still in use today, and across Europe, around 17% of all aluminium is used in packaging [1].

Major markets in the personal care sector for aerosol cans include deodorants, body sprays anti antiperspirants, hair products, shaving lather and household cleaners. The booming demand for aluminium aerosol cans worldwide continued in 2010 and reached a new production record in 2011 with some 6.6 billion cans produced worldwide [2] as demand in Europe recorded a rise of 13%. In the UK alone, 1.23 billion aerosol filling units were manufactured in 2009, with an estimated retail sales value of £935 million [1]. Despite a difficult economic climate, personal care continues to show resilience overall and it is expected to see further potential for growth not only in the cosmetics sector but also in other fields like the pharmaceutical and food industries, where the aerosol can has only played a minor role as a packaging material up till now.

This paper examines the use of simulation driven product design as a critical tool in enhancing aluminium can performance and designing new lightweight units. Aluminium cans are manufactured through a backward extrusion process of a cylindrical thin slug at ambient temperature. The can undergoes a complex shaping procedure to form a variable thickness can shell, with much plastic work and hardening experienced by the can material, resulting in non-constant properties. Most cans have bases that curve inwards to strengthen the structure of the can under inner pressure. The inverted base design (de-dome) is an inherent safety feature as it provides a visual indication of instability in the event of a pressure overload.

The can has to withstand a certain internal pressure which is specified by standards, such as European Packaging Qualification (ISO 90-3:2000) [3]. This is usually 20% below failure (burst) pressure as a safety factor. This is achieved by the optimal distribution of the can wall thickness. If the can is able to resist the internal

* Corresponding author. Address: Digital Technium, Room 008a, College of Engineering, Swansea University, Singleton Park, Swansea SA2 8PP, UK. Tel.: +44 (0)1792 606977.
E-mail address: f.belblidia@swansea.ac.uk (F. Belblidia).

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pressure larger than the safety factor, it is than possible to reduce the thickness (at specific locations) and save material. Therefore, during the simulation process based on the finite element technique, the model should take into account such non-linear material behaviour and the temporal increase in the pressure loading. Thus, a time stepping procedure is required and a balance between CPU time, mesh quality and accuracy should be adequately reached.

Two types of algorithmic approaches, considering material and loading non-linearity, and large deformation, are known and both are available in the Ansys Software used in these simulations [4]. The first treats the numerical time stepping in an implicit manner, allowing for a large time step level to be utilised, whilst the second considers explicit calculations where time step level is subject to the Courant–Friedrichs–Lewy condition (related to mesh size). Usually, implicit calculations can deal with long time events, but diverge for large element distortion, whilst its explicit counterpart is efficient for short events and is able to predict cases with distorted elements, such as explosions, drop tests, impact and penetration. In the present study and due to the long-time loading conditions, the implicit method is considered under adequate time-step size.

Currently, industrial practice in aerosol can design seeking weight reduction is based on a 'trial and error' method and relies heavily on extensive knowledge and experience to match the desired can profile. Numerical simulations are therefore an ideal tool to achieve the desired (and optimum) can design, whilst reducing the manufacturing time and cost. The aim of this work is to ensure that the can fulfils two major packaging requirements (EU standards: [2]) related to pressure loading and top load. For the former, the specific can selected in this study should be able to hold a pressure of 12 bar without compromising its integrity and overall shape and should not burst under 20% excess of holding pressure (i.e.: 14.4 bar). For the later, the can wall should sustain a compressing top loading on the bead up to 981 N [2]. The present study is being benchmarked against experimental data to provide confidence in further simulations seeking can optimal design, mainly at the dome, as material is reduced whist fulfilling pressure and top loadings standards. Numerical findings on optimum design will be published once intellectual property and patent issues are cleared.

Due to the commercial impact of such work, few publications have been disseminated discussing details of the methodology used. One might cite the work carried by Hardy and Abdusslam [5] and Patten [6] on extrusion and forming process of aerosol can and optimisation. Similarly Fox [7] carry out a stress analysis of self-pressurized aerosol container using Ansys package. Yamazaki and his team have simulated beverage cans parts to enhance optimum lightweight design [8] and tooling system for can manufacturing though forming process. Moreover, Faraji et al. [9] run numerical and experimental investigation on back extrusion processing of a magnesium alloy to determine the effects of die stroke and punch dimension on the plastic deformation behaviour. Recently, Niknejad and Tavassolimanesh [10] introduced a model of plastic deformation during the inversion process on the capped-end frusta using a solid cylindrical punch. However, the authors failed to identify similar work to that presented here for comparison purposes. There is an excessive list of published papers on container buckling and drop test analysis, where LsDyna and Abaqus commercial software have been widely used.

2. Can experimental and simulation data

A series of experimental trials were conducted on manufactured cans. These include pressure loading tests following a specific loading history and compressive top load tests at a specific speed. These tests are used to benchmark the numerical predictions.

2.1. Can design

The desired can profile design is provided by the manufacturer as a CAD model, as shown in Fig. 1. The can overall height is about 180 mm. The can is designed having two main wall, a lower cylindrical wall of 50 mm in diameter and upper shaped wall in a form of a waist of 40.0 mm diameter. The upper wall is linked to a conical top section (shoulder) through a gorge of 46.3 mm diameter and 16 mm in height. The shoulder ends with a bead ring section to hold the cap and can nozzle/seal. The bead ring external diameter is 31.3 mm. The can model used is designed to contain 200 ml of deodorant aerosol.

2.2. Can thickness and pressure loading

The can manufacturing starts with the extrusion of the aluminium slug during which the base and the cylindrical wall are formed. This is followed by reshaping the base by a backward extrusion to form the de-dome, resulting in a variable thickness of the thin de-dome base. The wall is also reshaped to generate a specific form (waist like), the shoulder and the bead, for all of which a variable thickness is obtained from these can parts.

A scan of the wall thickness of a manufactured can is provided in Fig. 2 and Table 1 for the de-dome and the wall region. Note, the cylindrical coordinate system (R) is used for the dome shape and the Cartesian counterpart (Y) is used for the longitudinal wall. The thickness data is paramount for a realistic simulation, as the study will highlight. This is novel approach as in many other analyses, the wall thickness is considered to be constant or piecewise constant.

2.3. Can material

Due to the can processing conditions, the degree of material work hardening will vary along the can wall, and in order to accurately describe the stress–strain characteristics throughout the models, it will be necessary to quantify these variations and their impact on material stress–strain characteristics. Such material data can be gathered by undertaking experimental tensile testing on selected samples, using an electrically-driven tensile test machine.

Thus, tensile tests were carried out at constant strain rate of 0.5 mm/min on samples cut from manufactured cans in the longitudinal and circumferential direction. Here, four locations in the longitudinal direction and four in the circumferential direction per can were designated for testing. The aim was to replicate the

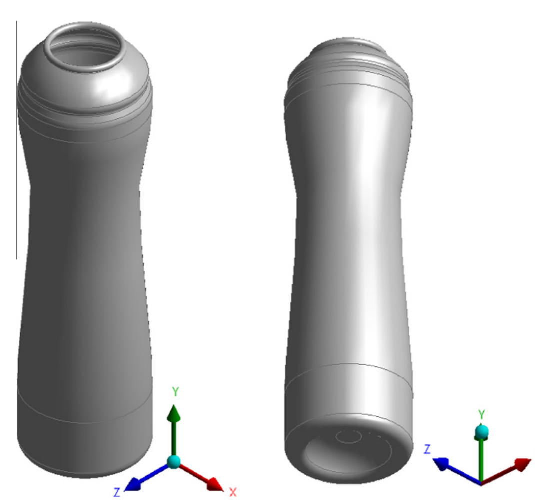

Fig. 1. CAD model of 200 ml aerosol can.