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Texture-based design of a convoluted cut-edge for earing-free beverage cans

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ABSTRACT

A texture-based earing model is applied to minimize earing of a 25 cl aluminium beverage can. Earing of can body stock was simulated by means of a polycrystal-plasticity model from the crystallographic texture of the sheet. The simulated earing profile was used to devise an optimized blank shape with minimum earing for the designated can geometry, and a convoluted cut-edge was produced accordingly. The earing patterns of the resulting intermediate cups and final cans were compared with their counterparts produced with a conventional round tool, demonstrating that the optimized blank shape quite efficiently reduced earing. The underlying assumption that an earing-free cup will actually lead to an earing-free can is discussed.

1. Introduction

Aluminium beverage cans are generally produced through a mechanical cold forming process that starts from large coils of cold-rolled sheet with a thickness of 0.25–0.3 mm. This sheet is typically an Al-alloy with about 1% manganese and 1% magnesium (Hirsch, 2006), which is referred to as alloy AA 3104 or EN-AW 3104. In order to meet the strength requirements for beverage cans, can body stock AA 3104 is used in the heavily strain hardened, hard rolled H19 temper.

The process of manufacturing cans is described in detail by Hosford and Duncan (1994). At the can manufacturing plant the Al-sheet is fed continuously from an uncoiler into a cupping press, the cupper, which stamps out thousands of discs per minute with up to 14 parallel tools. At first each individual tool cuts out a blank, then the drawing ram presses this blank through the draw ring to form a shallow cup. Fig. 1(a) shows the production cup of the well-known 33 cl beverage can. It is seen that the rim of this cup is not perfectly flat, but shows a number of small ripples at the top of the cup, known as 'ears', balanced by an equal number of low points, called 'troughs'. As will be addressed in more detail later in this paper, this so-called earing phenomenon is an unavoidable effect due to the plastic anisotropy of the heavily cold-rolled Al sheet.

In the next processing step the cups are fed into the body-maker. The cup is placed in front of a moving punch, which first pushes the cup through the redraw ring to reduce its diameter to the punch diameter whilst retaining the sheet thickness. The punch then forces the redraw cup through a series of three ironing rings with decreasing diameter. This reduces the thickness of the metal (wall ironing) and, as a result, stretches the cup walls. At the end of the stroke the can base is formed in an inverse drawing operation by the base panelling tool and the can is removed from the punch (Fig. 1(b)). The entire punch stroke of the body-maker – the so-called "redraw-and-ironing" operation – is done within fractions of a second. Subsequently the trimmer cuts off the can to the correct height and, especially, to remove the ears forming during the previous forming operations, leaving the upper wall straight and level. Then, the cans are washed and coated. Finally, the cans are passed through a necker/flanger, which gives them the characteristic neck shape. The diameter of the top of the can is reduced or 'necked-in'. The top of the can is flanged outwards to enable the end to be seamed on after the cans are filled.

It is known that one of the main constraints of Al sheet for the production of beverage cans is the occurrence of earing during the manufacturing of the cans, see, e.g. Ren (1998) and Engler and Hirsch (2007). Earing is highly undesirable since it requires extra metal to be trimmed from the top of the can, leading to loss of material. More severely, too pronounced earing is detrimental for cup and can handling and affects the process of can-making negatively, by stretching and clipping off ears, leading to machine down time and, hence, reduction of line-efficiency.

Earing of can body stock is primarily caused by the material's planar anisotropy, which is acquired during the thermo-mechanical production of the sheet, resulting in different material

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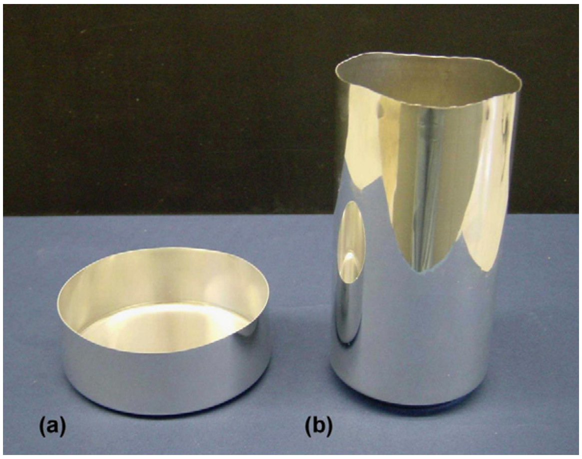

Fig. 1. Steps in manufacture of Al beverage cans, (a) deep-drawn cup and (b) un-trimmed can after redraw-and-ironing (33 cl standard can).

characteristics along different in-plane directions of the rolled sheet. With the help of suitable rolling schedules aluminium industry has been able to reduce the amount of earing to a level that is acceptable for the production of beverage cans. In short, a sufficiently strong cube texture of the recrystallized hot strip can balance the 45° ears forming upon cold rolling to final gauge; for more details see Hutchinson et al. (1989), Cheng (2001) and Engler et al. (2007).

An alternative approach to reduce the earing problem is to find an initial blank shape, referred to as the optimal blank shape, which leads to an ear-free product with uniform flange. Roughly speaking, at the positions of the blank where ears will develop during deep-drawing, material is removed from the blank, whereas there is extra material added to the blank which is able to fill the troughs. An experimental trial-and-error process to determine the best blank shape is very expensive and time-consuming. Therefore, numerical simulations present an attractive and effective alternative for the design of such "convoluted cut-edges". In particular when a fast blank optimisation is required for rapid reaction to a customer's request, a fast and reliable numerical blank design tool is necessary.

In the literature there are a number of approaches to determine the optimum blank shape upon sheet forming; detailed literature surveys on the methods have been given by Pegada et al. (2002) and Wang et al. (2009). Nowadays, most approaches are based on finite-element analysis, FEA (e.g. Chung et al., 1997; Dick et al., 2007). In order to account for the anisotropic properties of the sheet, the plastic behaviour is described by a phenomenological yield function. However, the accuracy achieved with this method is often not satisfactory, mainly as a result of inaccurate material models. In particular, most phenomenological yield functions fail in predicting more complex earing profiles with six or eight ears as typically observed in Al can body stock (see below). It has only recently become possible to predict six and eight-fold earing by using advanced yield functions, e.g. Yoon et al. (2006), Aretz et al. (2010) and J.-H. Yoon et al. (2010).

The present study has pursued a different approach: It is well established that plastic anisotropy of Al sheet, including the earing phenomenon, is caused by the crystallographic texture of the sheet. Accordingly, for simple load cases with axial symmetry such as in cup deep-drawing some aspects of plastic flow – especially those related to plastic anisotropy – can directly be modelled with the help of polycrystal-plasticity codes like the familiar Taylor model. Engler and Kalz (2004) have recently devised a texture-based polycrystal-plasticity model to tackle earing which was later shown to be able to predicting earing profiles of Al can body stock with great accuracy (Engler et al., 2007; Engler and Hirsch, 2007). In

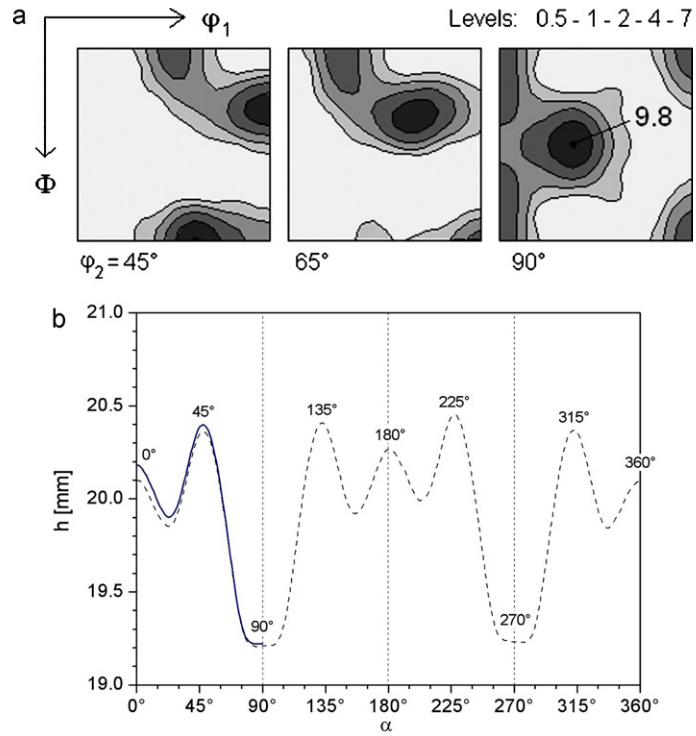

Fig. 2. (a) Texture and (b) earing profile of as-rolled AA 3104-H19 with six ears.

the present study this polycrystal-plasticity earing model was utilized to minimize the earing behaviour of a new 25 cl aluminium slim can. The texture-based earing profile was used to design an optimized blank shape with minimum earing for the new can geometry, and a convoluted cut-edge was produced accordingly. The earing patterns of the resulting cups and final (un-trimmed) cans were compared with their counterparts produced with a standard round tool.

It is noted that the texture-based polycrystal-plasticity model is set up to tackle earing upon deep-drawing. Therefore, the model was applied to simulate – and in turn minimize – earing in the intermediate cup, which obviously does not mean that the final can has to be free of ears as well. However, it is known that the overall earing tendency increases during deep-drawing and redrawing, but will decrease again through the subsequent ironing steps (J.W. Yoon et al., 2010). That is why we suppose that the earing level after the first drawing operation and that in the final cans should be comparable. The validity of this implicit assumption that an earing-free *cup* automatically leads to an earing-free *can* is addressed in the discussion.

2. Material and experimental methods

The experiments were conducted with standard can body stock AA3104 (Al–1%Mn–1%Mg) with a thickness of 0.245 mm. Fig. 2(a) shows the crystallographic texture of the material, presented in form of three characteristic sections through the 3D-orientation space (for details of measuring and representing textures, see Engler and Randle, 2010). For the production of beverage cans highly cold-rolled states (H19) are used to meet the strength requirements (>275 MPa). Therefore, the sheet comprises a pronounced rolling texture, where the crystallographic orientations are assembled along the so-called β-fibre which runs from the Cu-orientation $\sim\{1\,1\,2\}\langle 1\,1\,1\rangle$ through the S-orientation $\sim\{1\,2\,3\}\langle 6\,3\,4\rangle$ to the Bs-orientation $\sim\{0\,1\,1\}\langle 2\,1\,1\rangle$ through orientation space.