LS-DYNA USED TO ANALYZE THE MANUFACTURING OF THIN WALLED CANS

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ABSTRACT

The ironing process and the backward can extrusion process are widely used for the manufacturing of thin walled cans. In the ironing process the die is commonly made with a cylindrical die land and in backward can extrusion the punch is commonly made with a cylindrical punch land.

LS-Dyna has been used in the analysis of the influence, which the die land and the punch land have. The results suggest that a small misalignment of the die land, respectively the punch land may cause the process to become unstable resulting in uneven can height and uneven can wall thickness. Simulations also suggest that it is possible, by making minor changes to the geometry of the die land respectively the punch land, to make the process significantly more robust with regard to the influence from a small misalignment of the land.

The results obtained from the LS-Dyna simulations are in good agreement with experimentally obtained results.

KEYWORDS:

Ironing, Backward can extrusion, FEM, Process robustness

INTRODUCTION

Billions of thin walled aluminum cans (e.g. soft drink cans, aerosol cans) are produced annually and any improvements in the can making processes are thus of industrial importance.

Thin walled aluminum cans are either made from sheet material by deep drawing and ironing or by backward can extrusion. Figure shows a sketch of the ironing process and the backward can extrusion process.

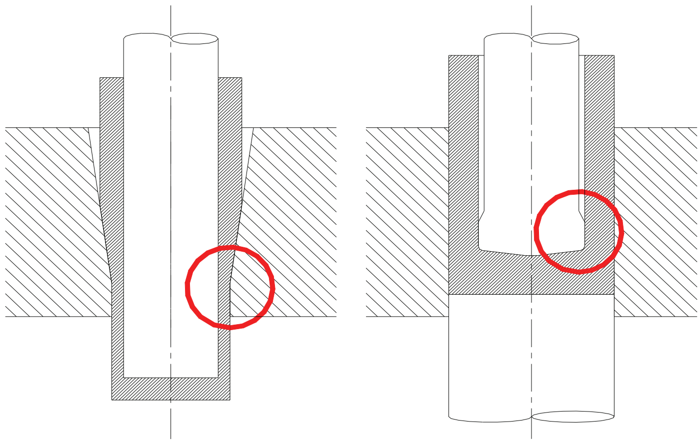

Figure 1 Sketch of the ironing process (left) and the backward can extrusion process (right). The part of the tool within the circle is commonly cylindrical; the part is denoted die land in case of ironing and punch land in case of backward can extrusion

In ironing the most common problems/defects are uneven can wall thickness, uneven can height and fracture in the can wall. In backward can extrusion one of the most common defects is according to [1] variation in the can wall thickness (eccentricity). Despite the industrial importance of both the ironing process and the backward can extrusion process very little has been published regarding why production problems/defects occur and what can be done to overcome and/or reduce the problems.

LS-Dyna has been employed in the analysis of the ironing process and the backward can extrusion process. The results obtained show that the die land and the punch land (see Figure) may have a significant influence on the robustness of processes and that the production problems/defects in some cases can be attributed to a slight misalignment of land (die land or punch land). Simulations also show that very minor changes in the geometry of the land (common industrial practice is to make the die land and the punch land cylindrical) can increase the process robustness significantly. A more detailed description of the research work carried out can be found in [2].

ANALYSIS OF THE IRONING PROCESS

Figure shows a sketch of the ironing process in which the die land is misaligned in relation to the punch (in the sketch the misalignment is highly exaggerated). A misalignment of the die land may be caused by e.g. inaccurate machining of the die, inaccurate mounting of the tools in the press and/or elastic deformation of the press. Due to the misalignment of the die land, contact between the can wall and the die will be lost on side A. The loss of contact will reduce the radial force on the die on side A compared to the radial force on the die on the opposite side, side B, and the hypothesis was that this will cause a net radial force on the die, which will move the die in radial direction in relation to the punch. To test this hypothesis the ironing of a thin walled can was analyzed using the slab method and 2D and 3D FEM simulations were carried out; here only the results from the 3D FEM simulations will be shown. Figure 3 shows the FEM model. Due to symmetry the model was made as a half model. The main parameters used in the simulation were as follows: initial can wall thickness 0.2 mm, punch radius 10 mm, reduction ratio 25%, elasto-plastic can material with constant yield stress, Coulomb friction in all interfaces with the friction coefficient $\mu = 0.1$, semi-die angle 13^0, length of die land 1 mm. The can wall was modeled using 8 node solid elements with 5 elements though the thickness. The total number of solid elements was 264000. The die and the punch were modeled as rigid using rigid shells. To simulate the effect of a misalignment of the die this was rotated 0.4^0 in relation to the punch and was prescribed a vertical velocity. The lower nodes of the can wall and the punch were constrained not to move vertically but free to move in radial direction. Figure 4 shows a close up of the

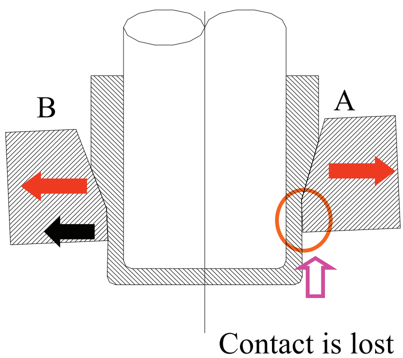

Figure 2: Ironing with a misaligned die. Due to the misalignment contact between the die land and the can wall is lost on side A.

die where contact between can wall and die land is lost due to the misalignment. To capture the effect of the misalignment the node penetration in the can wall-die interface had to be significantly smaller than 0.007 mm. Simulations were carried out with different penalty based contact algorithms and different penalty factors, but it was not possible to obtain a sufficiently small node penetration using a penalty based contact algorithm. Instead the constrained based contact algorithm *CONTACT_CONSTRAINT_SURFACE_TO_SURFACE was used. Using this contact algorithm there was hardly any node penetration in the can wall-die interface.

If it is true that a small misalignment of the die has a significant influence when a conventional die with a cylindrical die land is used, an obvious question is how the geometry of the die should be in order to reduce the influence from a slight misalignment of the die. If the die is made circular profiled a small misalignment will only have minor influence on the contact condition is the die-can wall interface. To test the hypothesis that a small misalignment will only have a minor influence when the die is made circular profiled a 3D FEM model similar to the FEM model shown in figure 3 was made, the only difference was that the conventional die was replaced with a circular profiled die having a radius of 20 mm. FEM simulations were carried out with the circular profiled die rotated 0.4^0 in relation to the punch.

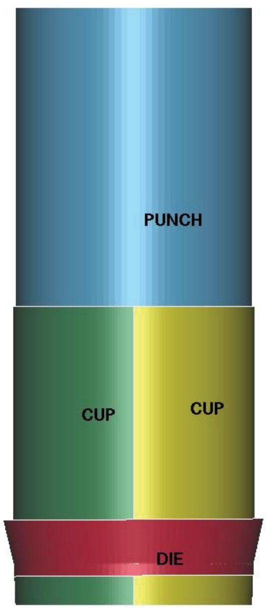

Figure 3 3D FEM model of the ironing of a thin walled can carried out with a conventional die with a cylindrical die land.

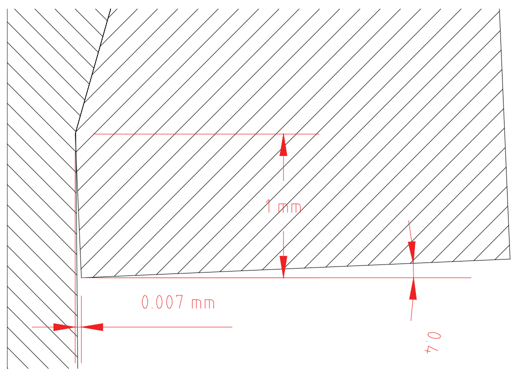

Figure 4 Close up of the region of the ironing die where contact is lost due to the misalignment between die and punch (the die is rotated 0.4^0 in relation to the punch).

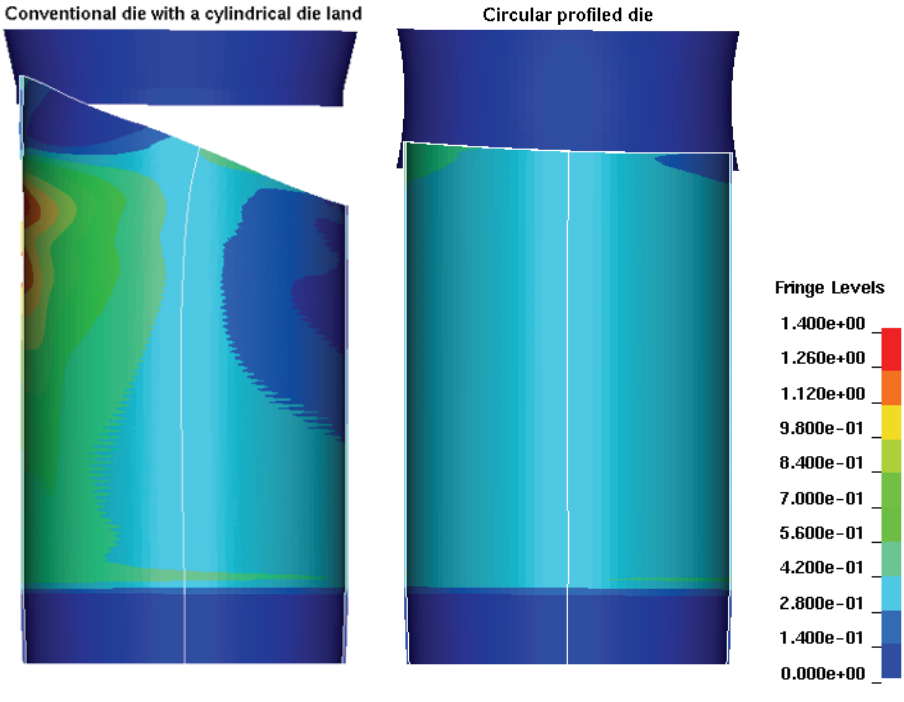

Figure 5 The equivalent strain distribution in the can ironed with a conventional die with a cylindrical die land (left) and with a circular profiled die land (right). In both cases the die was rotated 0.4^0 in relation to the punch.

It is clear from figure 5 that the FEM simulations support the hypotheses a) that a small misalignment of the die in relation to the punch has a significant influence if the die land is cylindrical and b) that the influence from a misalignment can be reduced significantly if the die is made circular profiled. From figure 5 it can also be seen that the inhomogeneous strain distribution in case of the conventional die with the cylindrical die land is constrained to the upper part of the can wall. The reason for this is believed to be as follows: if the reduction ratio is to increase on one side and decrease on the opposite side, the can wall above the ironing die must move faster in vertical direction where the reduction ratio increases than on the opposite side where the reduction ratio decreases (provided that can wall does not fracture or wrinkles). However the can wall above the ironing die will resist such a velocity difference and

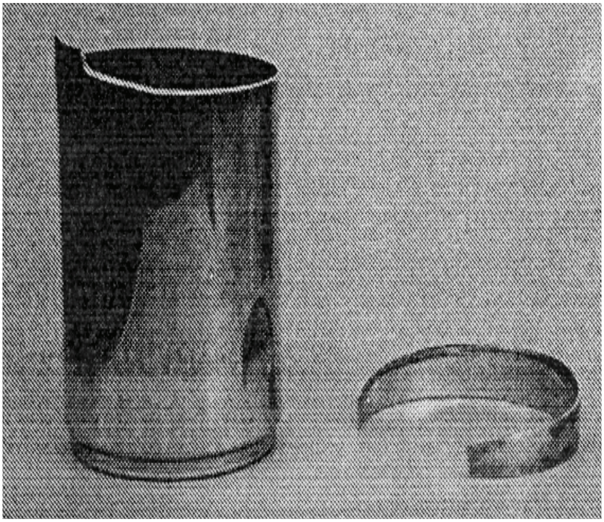

Figure 6 Fracture in the upper part of an ironed stainless steel can [3].

only when there is a "limited" amount of can wall above the die (and thus a limited amount of material to deform to facilitate a velocity difference) can the reduction ratio increase on one side and decrease on the opposite side. The FEM simulation showed that a bulge is formed above the die land on the side where the reduction ratio tends to increase (the left side). This bulge increases the radial force on the die and balances the radial forces such the ironing process remains fairly stable. The bulge also gives rise to vertical compressive stresses in the can wall above the ironing die, and towards the end of the ironing process, these vertical compressive stresses can plastically deform the can wall above the ironing die with the effect that the reduction ratio increases on one side and decreases on the opposite side. The increase in reduction ratio may become so large that the can wall fractures. In an experimental investigation of the ironing of thin walled stainless steel cans [3], fracture as shown in Figure occurred in upper part of the can wall from time to time. Qualitatively there is very good agreement between the FEM results, figure 5 left, and the fracture in the upper part of the can wall observed experimentally, Figure 6.

ANALYSIS OF THE BACKWARD CAN EXTRUSION PROCESS

The punch used in backward can extrusion is commonly made with a cylindrical punch land as also recommended by the International Cold Forging Group [4]. In backward can extrusion a slight misalignment of the punch land has a similar effect as a slight misalignment of the die land in ironing. Figure 7 shows a sketch of backward can extrusion where the punch land is misaligned (the misalignment is highly exaggerated in the Figure). Due to the misalignment contact between can wall and punch land is completely lost on side A, whereas on side B a small misalignment will only have a marginal effect on the contact condition. This difference in contact condition on side A and side B will create a net radial force on the punch, which will try to deflect the punch to the right increasing the wall thickness on side B and decreasing the wall thickness correspondingly on side A.

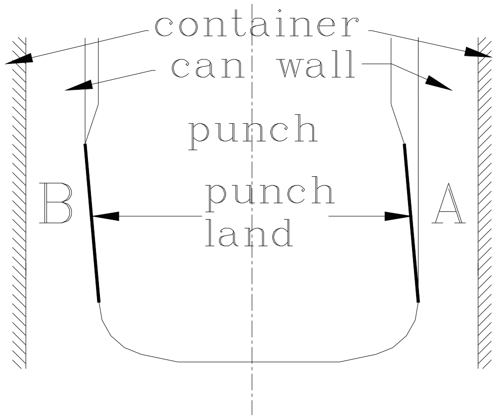

Figure 7 Sketch of backward can extrusion with misalignment of the punch land in relation to the punch shaft.

As with ironing the hypothesis was that the effect of a slight misalignment of the punch land can be reduced if the punch land is made e.g. circular profiled instead of being cylindrical. The hypotheses that a slight misalignment of the punch land, if this is cylindrical, will cause the can to become eccentric and that the effect of a slight misalignment can be reduced if the punch land is made circular profiled were investigated using the slab method and using LS-Dyna. Here some of the results obtained from 2D rotational symmetric simulations will be presented. A more detailed description of the simulations carried out can be found in [2]. Figure 8 shows the 2D rotational symmetric FEM model of backward can extrusion with a punch with a cylindrical punch land. The FEM model of backward can extrusion with the circular profiled punch land was besides from the geometry of the punch land identical to the FEM model shown in figure 8.

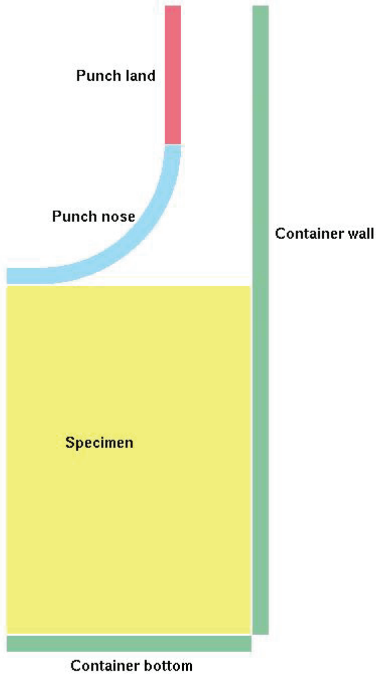

Figure 8 2D rotational symmetric FEM model of backward can extrusion.

The tool parts were made as rigid bodies with 4 node elements. The specimen was modeled as an elasto – perfectly plastic material with the yield stress = 100 MPa.

The friction in the contact surfaces was modeled as a combination of Coulomb friction with friction coefficient μ = 0.15 and constant friction with the friction factor m = 0.15; for low surface pressure Coulomb friction was used and for high surface pressure the constant friction was used. The contact algorithm used was *CONTACT_ AUTOMATIC_2D_SURFACE_TO_SURFACE. To the experience of the author this contact algorithm is more robust than *CONTACT_AUTOMATIC_2D_NODE_TO_ SURFACE.

To overcome problems with mesh distortion remeshing was employed. During each simulation automatic remeshing was carried out at constant time intervals (100 remeshings in each simulation). The number of elements in the specimen was of the order 7500.

To investigate the effect of a slight misalignment of the punch land simulations were carried out with the punch land tilted $+0.4^0$ and -0.4^0. Figure 9 shows the radial force on the punch land as function of the punch displacement with the shape of the punch land as parameter (the curves in figure 9 have been smoothed).

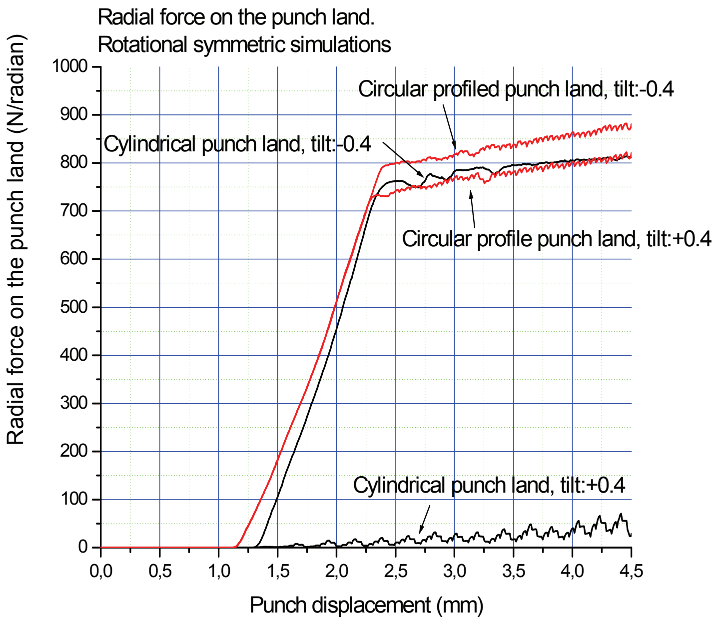

Figure 9 The radial force on the punch land as function of punch displacement and with the shape of and tilt angle of the punch land as parameter.

With the conventional cylindrical punch land the difference in the radial force on the punch land due to the change in tilt is approximately 780 N/radian (for a punch displacement of 3.5 mm). The corresponding difference with the circular profiled punch land is approximately 60 N/radian. The 2D rotational symmetric simulations thus support the hypotheses that

- if the punch is made with a cylindrical punch land a small misalignment of the punch land can give rise to a significant radial force on the punch.
- if the punch is made with a circular profiled punch land a small misalignment of the punch land will give rise to a radial force on the punch, which is significantly smaller than when a punch with a cylindrical punch land is employed.

EXPERIMENTAL INVESTIGATIONS

The backward extrusion of 250 mm high aluminum can with an outside diameter of 73 mm and a nominal can wall thickness of 0.915 mm from a slug with a diameter of 72.8 mm and height 15.1 mm was investigated experimentally. 10 cans were produced with a punch having a cylindrical punch land and 12 cans produced with a punch having a circular profiled punch land; in the experiments main emphasis was placed on keeping everything the same (besides from the geometry of the punch nose).

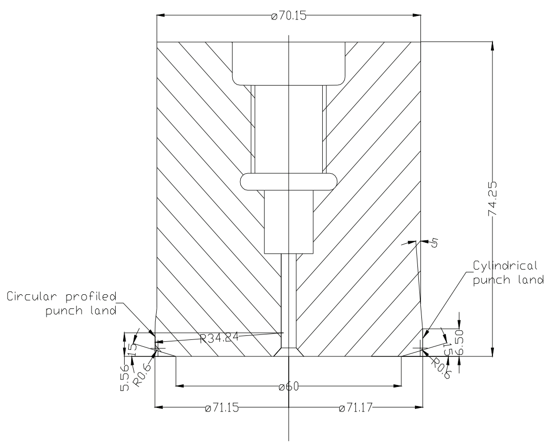

Figure 1 The punch geometries used. To the left with the circular profiled punch land and to the right with the cylindrical punch land.

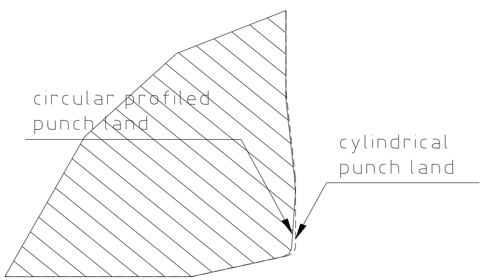

Figure 11 The cylindrical punch land and the circular profiled punch land drawn together.

Figure 10 shows the geometry of the two punches; the left half the punch with the circular profiled punch land and the right half the punch with the cylindrical punch land.

In figure 11 the geometry of the two punches are drawn together; as can be seen there is only very minor difference in the geometry, and it may be hard to believe that such a small difference can have any influence on the can wall thickness, but it has.

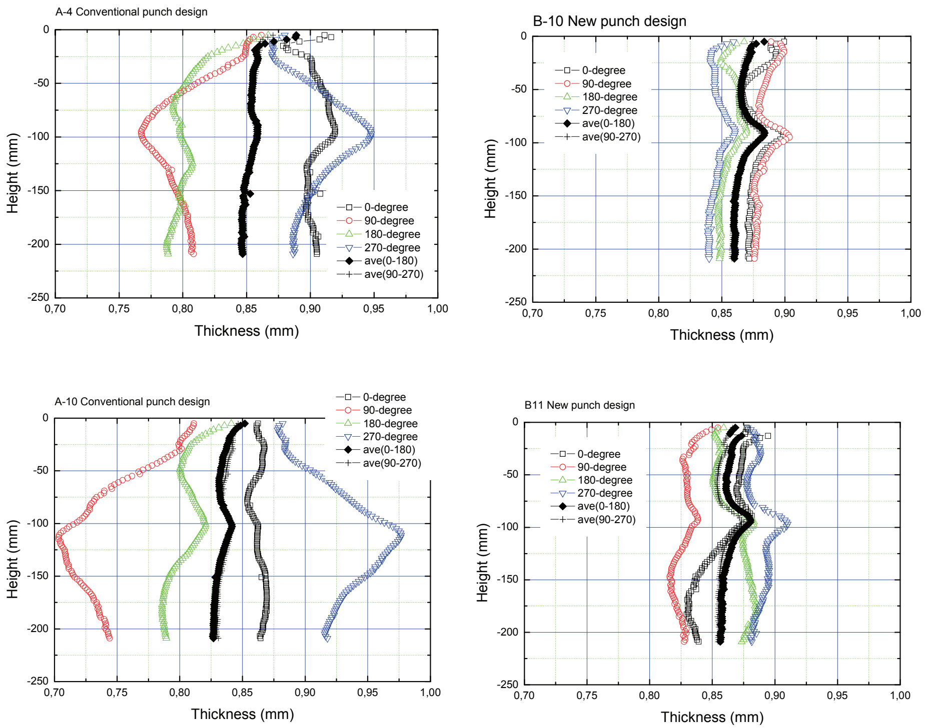

Figure 12 The can wall thickness in cans produced with the conventional punch with the cylindrical pun land (left Figures) and with the punch with the circular profiled punch land (right Figures). The upper Figures are the cans with the smallest variation in thickness and the lower Figures with the largest variation.

The wall thickness of the extruded cans was measured using a 3D coordinate measuring machine. The can wall thickness was measured in vertical direction for every 2 mm in 0^0, 90^0, 180^0 and 270^0 from 5 mm to 209 mm below the can rim. (0^0: the direction with the smallest can height). Figure 12 shows the measured wall thickness measured in the 4 directions as function of the distance from the can rim in the can showing the smallest (upper Figures) and the largest thickness variation (lower Figures) in the cans produced with the conventional punch with the cylindrical punch land (left Figures) and in the cans produced with the punch with the circular profiled punch land (right Figures). Also shown is the average of the measured can wall thickness in 0^0 and 180^0 and in 90^0 and 270^0.

From figure 12 it is clear that the shape of the punch land has had a significant influence on the wall thickness variation; the variations are substantially decreased using the punch with the circular profiled punch land compared to when using the conventional punch with the cylindrical punch land. The average thickness variation Δt_{ave} for the cans in each series was:

cylindrical punch land:

Δt_{ave} = 0.238 mm (s.d. 0.016 mm)

circular profiled punch land

Δt_{ave} = 0.092 mm (s.d. 0.018 mm)

where

$$\Delta t_{ave} = \frac{\sum_{1}^{n} (t_{max,i} - t_{min,i})}{n}$$

n: number of cans in each series

$t_{max,i}$, $t_{min,\,i}$: the maximum, respectively the minimum wall thickness in can no. i.

INDUSTRIAL APPLICATION

The use of a circular profiled punch land is currently being tested in industrial production of a 175 mm long aluminum can with a can wall thickness of 5 mm. The can is used in the steering column in many European cars. The experience so far is

- the average wall thickness variation is reduced from 0.32 mm to 0.14 mm
- the maximum wall thickness variation is reduced from 0.5 mm to 0.27 mm
- the tool is much faster to mount in the press because the tool is very insensitive to misalignment errors between the upper and lower part of the tool.

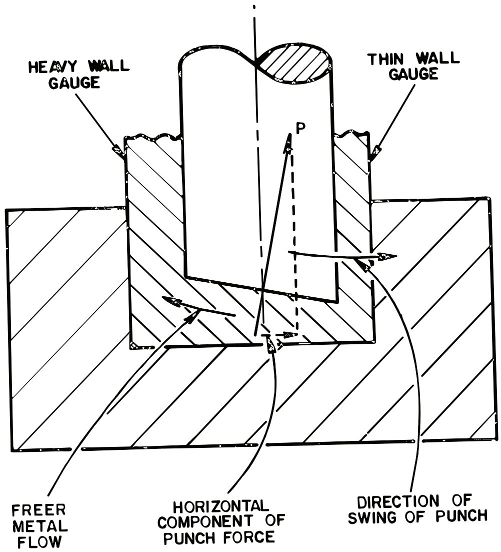

Figure 13 Cause of eccentricity in backward can extrusion according to Avitzur [1].

According to Avitzur [1] the most obvious cause of eccentricity is a misalignment of the punch face in relation to the punch shaft as shown in figure 13; if the punch face is not orthogonal to the punch shaft the material beneath the punch face can flow more freely to the left and the radial force on the punch face will swing the punch to the right.

In the opinion of the author a much more likely explanation for eccentricity problems in backward can extrusion is a misalignment of the cylindrical punch land.

CONCLUSIONS

Both the ironing die and the backward can extrusion punch is commonly made with a cylindrical land, die land respectively punch land. The influence, which a small misalignment of the land has, has been investigated using the slab method, FEM simulations and experiments. The results show that a small misalignment has a significant influence on the process robustness. In ironing a misalignment causes a very inhomogeneous strain distribution in the upper part of the ironed can, a very uneven thickness distribution and may also cause fracture. In backward can extrusion a small misalignment causes the can to become very eccentric. The reason why a small misalignment has such a significant influence is because the misalignment causes a drastic change in the contact condition between can wall and land in the region where the misalignment gives rise to a complete loss of contact between can wall and land.

By making the land circular profiled a small misalignment of the land will only have marginal influence on the contact conditions and thus only marginal influence on the quality of the cans produced. The 3D FEM simulations show that the ironing process becomes significantly more robust by making the die land circular profiled; the can produced is nearly unaffected by a small misalignment of the die land. 2D rotational symmetric simulations and experiments show that in backward can extrusion the wall thickness variation can be reduced significantly by making the punch land circular profiled instead of cylindrical. The results thus strongly suggest that the punch land should not be made cylindrical as recommended by the International Cold Forging Group [4]. It is thought-provoking that the worst geometry the land can have (in the opinion of the author) is cylindrical, and in industry it is common practice to make the land cylindrical.

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