



## KKU Engineering Journal

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### The improvement in deep drawing process for producing air filter by using finite element method

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Received December 2011

Accepted August 2012

#### Abstract

This research had improved the production of filter in deep drawing process. By using finite element method, FEM, in the analysis, optimum products design could be achieved. The material SPCE with thickness of 0.6 mm. had been used to produce the cup with diameter 102 mm. and height 145 mm. High quantities of rejected products were discovered with crack defects, which caused the production to be less competitive with other companies. Therefore, the improvement of production design had been proposed to design the suitable processes. The production improvement processes involved 5 processes which design drawing ratio of  $\beta=1.5, 1.5, 1.1, 1.8$ , and 1.07 respectively.

In the analysis, the material properties had assumed to behave as elastic-plastic according to power law of Ludwik with  $K = 320 \text{ N/mm}^2$  and  $n = 0.085$ . According to Hill's the anisotropy of sheet metal were  $r_0 = 1.87$ ,  $r_{45} = 1.30$  and  $r_{90} = 2.14$ . From the results of FEM, the forming ability of high cup cannot be drawn within a single process. The part size should be reduced with suitable drawing ratio which decreased the least sheet thickness. The simulation results shown the strain on parts were within the forming limit diagram, which the lowest part thickness was 0.53 mm without damage occurred. Thus occurred stress and strain at fracture were comparable to the Gurson Model, GTN.

From the analysis of deep drawing process for producing filter, the production cost had been reduced such as die machining, die trial and error, materials wasted, labor cost, and machines power. The higher production quality and production efficiency can be observed, which will increase the company ability to compete in the future market. This investment in the modeling technology reflected in reduction of the manufacturing cost and increase the company benefits

**Keywords:** Deep drawing process, Finite element method, Drawing ratio

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## 1. Introduction

Deep drawing process is useful sheet metal forming methods that apply in industrial field for producing automotive parts, kitchen ware, furniture, etc. Modern products design had increasingly more complex shape which drive current deep drawing technologies to their limits. The effort to solve such problems has encountered to improve sheet material mechanical properties, high tooling techniques, and process optimization design [1].

## 2. Deep Drawing Methods

In deep drawing a sheet metal blank is drawn over a die by a radius of punch. As the blank is drawn radially inwards the flange undergoes radial tension and circumferential compression. The latter may cause damage of crack at the flange if the draw ratio is large, or if the cup diameter-to-thickness ratio is high. The drawing ratio is the comparison of blank diameter and punch diameter in which greater difference in ratio may cause higher stretch of metal sheet. A blank-holder usually applies sufficient pressure on the blank to prevent wrinkling that usually occurred before crack initiated. Radial tensile stress on the flange being drawn is produced by the tension on the cup wall induced by the punch force. Hence, when drawing cups at larger draw ratios, larger radial tension are created on the flange and higher tensile stress is needed on the cup wall. Bending and unbending over the die radius is also provided by this tensile stress on the cup wall. In addition, the tension on the cup wall has to help to overcome frictional resistance, at the flange and at the die radius. As the tensile stress that the wall of the cup can withstand is limited to the ultimate tensile strength of the material, the draw ratio possible in deep drawing is usually limited to about 2.1 or 2.2 [2].

## 3. Finite element method

In this research, the filter as shown in Figure 1

had been studied by using finite element method, FEM. Thus the commercial software program AutoForm had been applied in the analysis. This program has applied triangular mesh with automatically meshing method in the large deformation area. The material SPCE with thickness of 0.6 mm were used to produce the cup with diameter 102 mm and height 145 mm

In the analysis, the material properties had assumed to behave as elastic-plastic according to power law of Ludwik with  $K = 320 \text{ N/mm}^2$  and  $n = 0.085$ . According to Hill's the anisotropy of sheet metal were  $r_0 = 1.87$ ,  $r_{45} = 1.30$  and  $r_{90} = 2.14$ . These input data base were reported from mechanical tensile test.

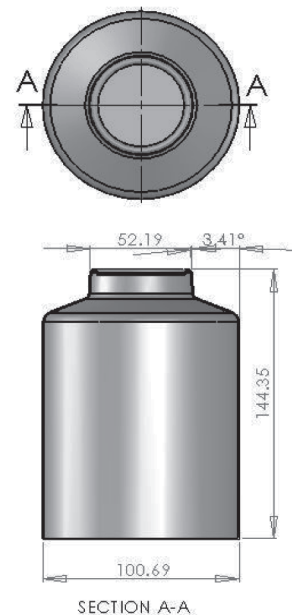


Figure 1 Filter drawing and dimension.

From the filter dimension, the diameter is much smaller than the height which indicated that the part has limited design with should provide suitable drawing ratio in the preformed stages in order to gradually increased the strain during forming.

#### 4. Results and discussion

In this productions, the determining of suitable drawing ratio were critically importance factors for successful forming. The previous manufacturer design were shown in Figure2 which consisted of drawing ratio for  $\beta = 1.63, 1.23$ , and  $1.23$  respectively. In this case, the preformed cup of the first stage and second stage had caused great reduction of the cup thickness as shown in the curve thickness Figure 2 which cup thickness of  $0.33$  mm finally fractured on the final stage.

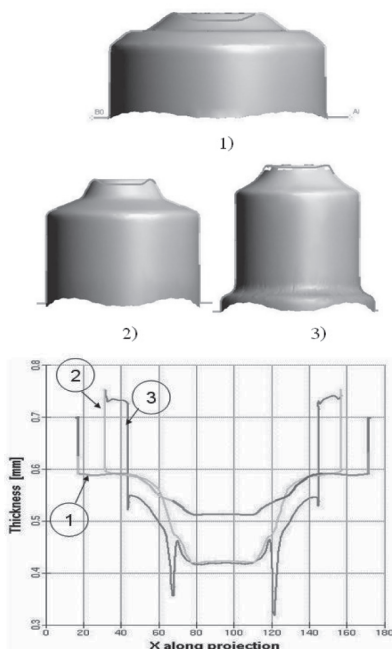


Figure 2 Three stages deep drawing and sectional thickness of parts [3].

Thickness is one of the major quality characteristics in sheet metal formed part. The thickness is unevenly distributed in the part after deep drawing. Generally, the thickness is uniform at the bottom face of the punch, minimum at the punch nose radius and vertical surface, and thicker at the flange area. Existence of thickness variation from the production stage may cause stress concentration in the part, leading to the acceleration of damage. The selection of appropriate process parameters and their

combination results in high quality parts [4]. The history of strain path during forming could be distinguished for successful for deep drawing process by showing on FLD.

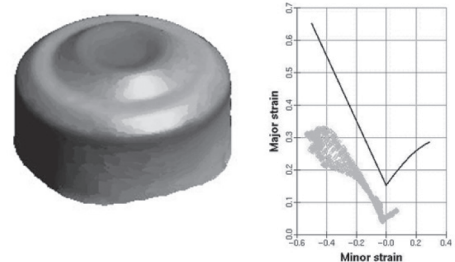


Figure 3 FLD for first draw.

The first stage preformed the blank size of diameter  $253$  mm to cup  $156$  mm, which caused lower strain localize around the top area. The strain still save under FLD curve as shown in Figure 3

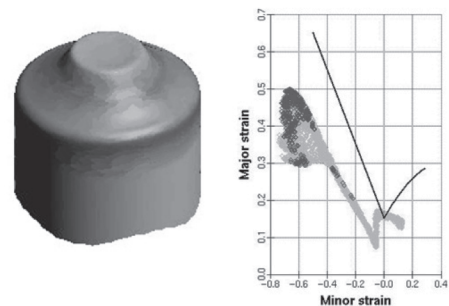


Figure 4 FLD for second draw.

The second stage preformed the cup  $156$  mm to  $126$  mm, which significantly caused high strain on the top area. The strain had reached FLD curve as shown in Figure 4

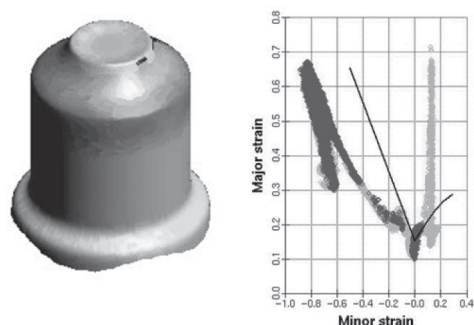


Figure 5 FLD for third draw.

The final stage of deep drawing cup 126 mm to 102 mm, a significant high strain had occurred on the top area that fracture finally appeared. The strain had raised above FLD curve as shown in Figure 5 This indicated that the second draw had increased the up to limited of material elongation and finally damage crack existed at further deformation in the third stage. In the improvement of the filter design, 5 processes which involve design drawing ratio of  $\beta=1.5, 1.5, 1.1, 1.8$ , and  $1.07$  respectively. In this case, the preformed cup of the every stages had gradually decreased the cup thickness as shown in the curve thickness Figure 6 which the lowest thickness was 0.53 mm

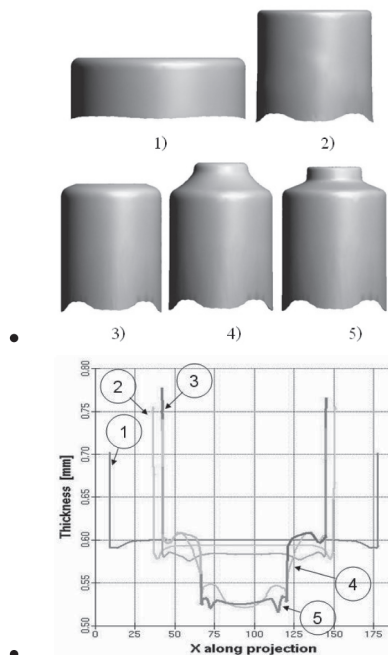


Figure 6 Five stages deep drawing and sectional thickness of parts.

The first improved stage preformed the blank size of diameter 253 mm to cup 168 mm, which caused lower strain to be localized around the top area. The strain still save under FLD curve as shown in Figure 7 This draw ratio was designed for performing part with small occurrence of strain.

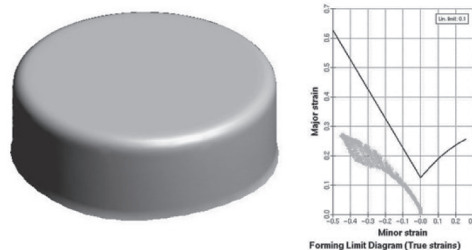


Figure 7 FLD for first draw improvement.

The second improved stage preformed the cup 168 mm to 112 mm, which caused lower strain to be localized around the top area. The strain still save under FLD curve as shown in Figure 8 At this stage, the draw ratio had been designed for smaller cup diameter reduction, while providing some limited ratio for the next stage.

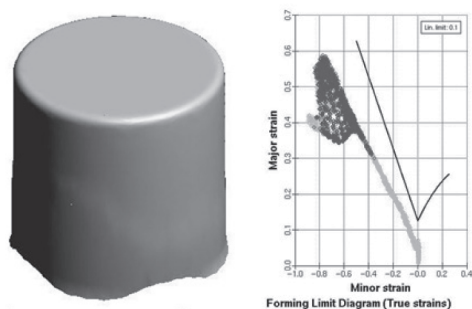


Figure 8 FLD for second draw improvement.

The third improved stage preformed the cup 112 mm to 102 mm, which caused lower strain to be localized around the top area. The strain still save under FLD curve as shown in Figure 9 This draw ratio cannot be design any higher which risk of damage of cup to initiated.

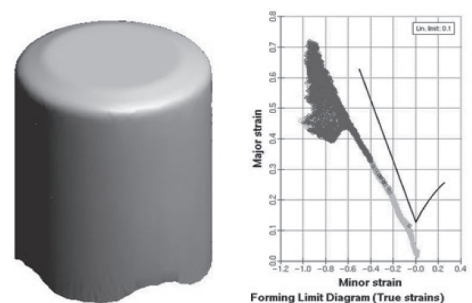


Figure 9 FLD for third draw improvement.

The forth improved stage preformed only the top part of the cup 102 mm to 54 mm, which caused strain to be localized around the top area. The strain appeared under FLD curve as shown in Figure 10. This stage had preformed only the top part

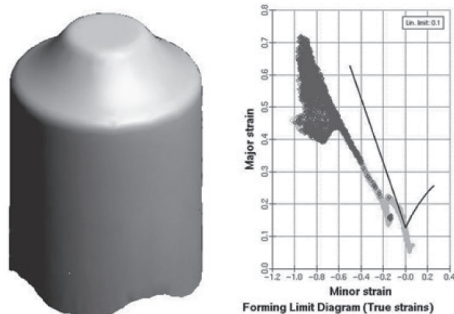


Figure 10 FLD for forth draw improvement.

The fifth improved stage finally formed only the top part of the cup 54 mm to 50 mm, which caused small increment of strain localized around the top area. The strain appeared on FLD curve as shown in Figure 11. At this stage, the filter had finally formed into shape throughout the progressive stages of drawing ratio.

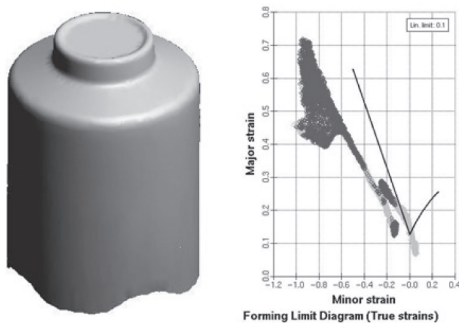
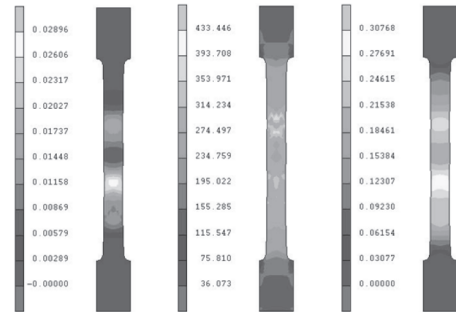


Figure 11 FLD for fifth draw improvement.

Similarly, the prediction of occurrence of fractures on sheet metal could be distinguished through Gurson Model, GTN, by considering the parameters such as  $q_1=1.5$ ,  $q_2=1$ ,  $f_{\text{initial}}=0$ ,  $f_{\text{critical}}=0.15$ ,  $f_{\text{failure}}=0.25$ , mean strain nucleation = 0.3, standard deviation = 0.1, and  $f_{\text{nucleation}}=0.04$  [5].



a) Void Volume Fraction = 0.01855

b) Von Mises Stress = 300 MPa

c) Equivalent Plastic Strain = 0.26 [6]

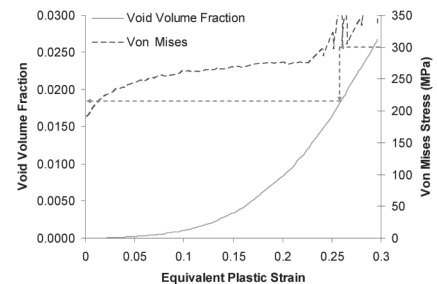


Figure 12 Comparison of curves path for Void Volume Fraction = 0.01855 at Von Mises Stress = 300 MPa and Equivalent Plastic Strain = 0.26

From the prediction of sheet metal deformation during tensile test as shown in contour plot on Figure 12 the fracture of specimen had occurred when Von Mises Stress reached 300 MPa, which equivalent plastic strain equal 0.26 and void volume fraction was 0.1855 as shown on plotted characteristic curves.

The plastic strain value for fracture at critical void volume fraction from GTN could be distinguished on the top corner radius of filter in sectional curves as shown in Figure 13

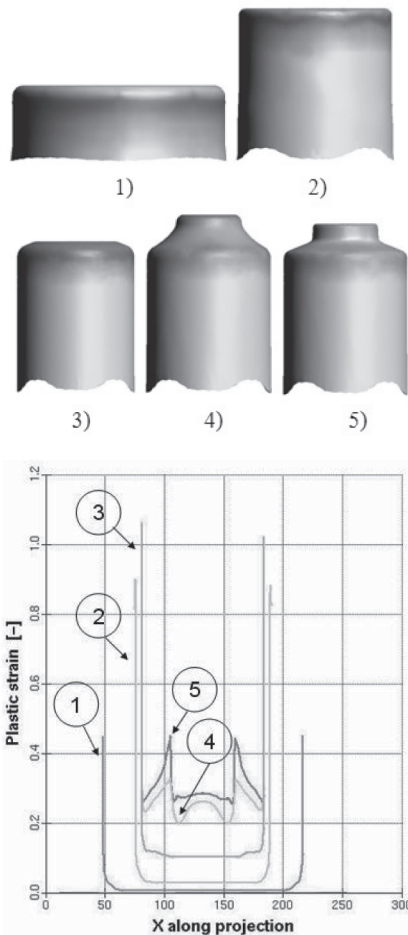


Figure 13 Plastic strain on part and sectional characteristic curves.

## 5. Conclusions

From this experiment, multi-stages for deep drawing processes had been studied. The prediction of the fracture limit and the forming limit during sheet metal forming process is very important in order to identify the conditions that deforming sheet may lead to ductile fracture[7]. For a given initial strain path, after the onset of strain localization, the material forms a neck which continue to deform by an almost plane strain path up to failures[8]. The success in the production for filter were selection of suitable design drawing ratio, which had improved the part quality through five progressively forming stages.

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