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Application of Numerical Simulations in the Deep-Drawing Process and the Holding System with Segments' Inserts

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The demands for complicated products have increased dramatically over the last few years taking into consideration the utilisation of sheet metal, product quality and process conditions. For reliable product development and stable production process, the use of FEM is necessary.

One of the most significant parameters in the sheet metal forming process is the blank holding force. In the research work, the optimisation of the blank holding force was performed with the help of FEM analysis. For the optimisation the geometry and the structure of the blank holder was optimised. The best results were obtained with flexible, segmented blank holders, which enables wider technological window for good parts.

Keywords: Sheet metal forming, deep drawing, segmented holding system, finite elements methods (FEM), optimization

0 INTRODUCTION

Sheet-metal forming and deep-drawing are well-known manufacturing processes. However all developers are of the same opinion that deep-drawing is a very complicated process. There are several factors, such as nonlinearity, large deformation, friction and material characteristics that have a direct influence on the process and are sensitive to each other. In addition, the tolerances of the input materials are very rough, which is an extra challenge for the developers. Therefore, tryouts of the dies are required within an actual industry, in order to find a technological window of good parts (Fig. 1). FEM analyses reduce this set-up time and the subsequent improvement in product quality without cracks, wrinkles and scratches is significant [1].

As can be seen from Fig. 1, holding-force is one of the more important parameters that influence the deep-drawing process and can be calculated using FEM analyses [2]. Therefore, with an appropriate approach, a better quality of the workpiece could be achieved, and the reaction forces on the main parts of the tool are smaller, thus achieving a longer life-time of the tool. FEM analyses can calculate different types of forming, such as hot-forming [3] and hydro-forming but this study only conducted conventional cold forming. There are also different holding systems such as holding with constant force, holding with time-dependent forces, and with segmented or distributed-holding forces [4] to [6]. A segmented holding system with segments' inserts was chosen for this study. These holding systems are rarely used in current household appliance production and the automotive industry [7].

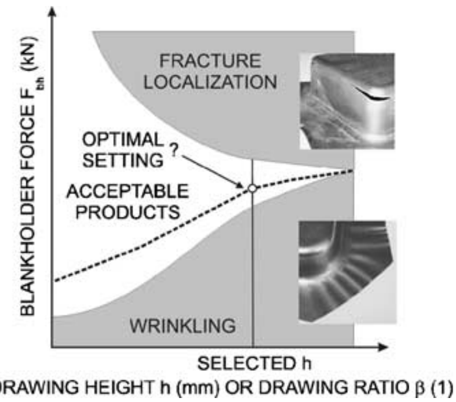

Fig. 1. *Technological window [1]*

The purpose of this work and analyses was to identify sensitive matrix between the holding forces and the qualities of the workpieces. Analyses were carried out with a FEM, and the Pam-Stamp software package was used for

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calculation. The first goal of this research was to determine the most appropriate holding system and the second to optimize blank holding forces (BHF) for the chosen holding system, by applying fuzzy logic [8].

1 NUMERICAL ANALYSES OF THE DEEP DRAWING PROCESSES

1.1 Product being Investigated

An asymmetrical workpiece was chosen from household appliances industry (Fig. 2). This workpiece is one of the component parts from a cooking device and was chosen because it looks simple. However, there were a lot of problems with it, especially with critical corner areas. This part has a valid special criterion because the part is visible on the end-product. No wrinkles, scratches or cracks are allowed.

The workpiece has a different depth of draw on both sides; on the higher side 36 mm and on the lower side 10 mm. The dimensions of the initial blank are 660×220×0.7 mm. The computer models are simplified and are shown in Fig. 3. The main parts of the computer model contain die, blank, blank holder, segments' inserts, and punch.

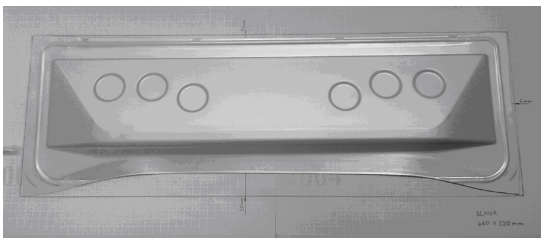


Fig. 2. *Workpiece*

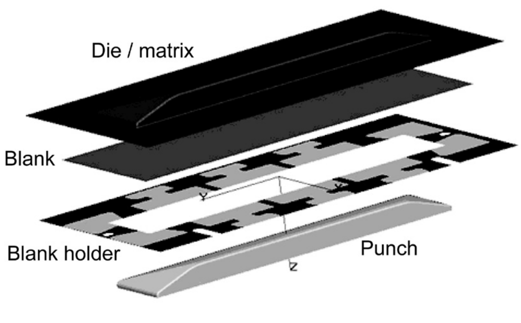


Fig. 3. *Computer model*

1.2 Basic Parameters

The surfaces of the die, punch, blank holder and segments' inserts were discretized, mainly by quadrangular surface elements and were assumed to be perfectly rigid. The blank was discretized by quadrangular surface elements and the plastic behaviour was discretized by Hollomon's hardening law.

The dynamic explicit approach was chosen for the calculation of the forming-process. Appropriate parameters such as friction, punch-velocity and drawing-radii were selected from the metal-forming handbooks and from previous research. These invariably geometrical parameters and process parameters are shown in Table 1. The maximal punch stroke or drawing height was 36 mm; any workpieces made with a drawing height of less than 36 mm were unacceptable.

Table 1. *Geometrical and process parameters*

Parameter	Value
Punch velocity	5 m/s
Drawing radii	1.8 mm
Punch stroke	36 mm
Friction coefficient	die/blank 0.1; punch/blank 0.12; holder/blank 0.1

1.3 Material Properties of Sheet Metal

A commercially-available DC04 sheet metal with a thickness of 0.7 mm was used for the blank material and tensile tests were conducted to determine the material properties. For the calculations Hill48 with orthotropic anisotropy was used. The material model coefficients were identified based on stress-strain curves (Table 2).

The material was defined by Hollomon's hardening law, and is given by i.e. (1):

$$\sigma_f = C \cdot \varphi_e^n, \tag{1}$$

where σ_f is yield stress, C is strength coefficient, φ_e is true strain, and n is hardening exponent.

Tensile tests were carried out on a Zwick/Roell 1474 machine based on SIST standard. The values are average values gained from five tests.

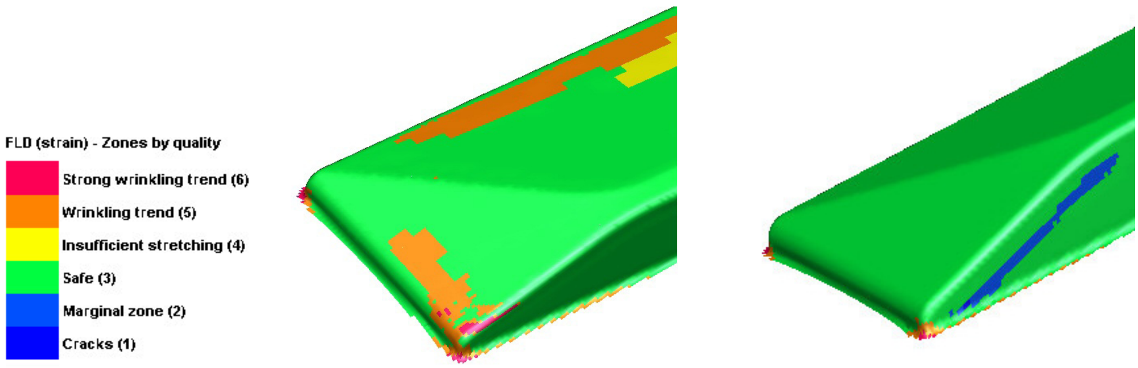
Table 2. *Material properties of sheet metal*

Blank material		DC04
Yield strength		188.9 N/mm²
Tensile strength		298.4 N/mm²
Elastic module		210000 N/mm²
Strength coefficient		384.98 N/mm²
Hardening exponent		0.21
Coefficient of anisotropy	0°	1.971
	45°	1.538
	90°	2.079

2 RESULTS

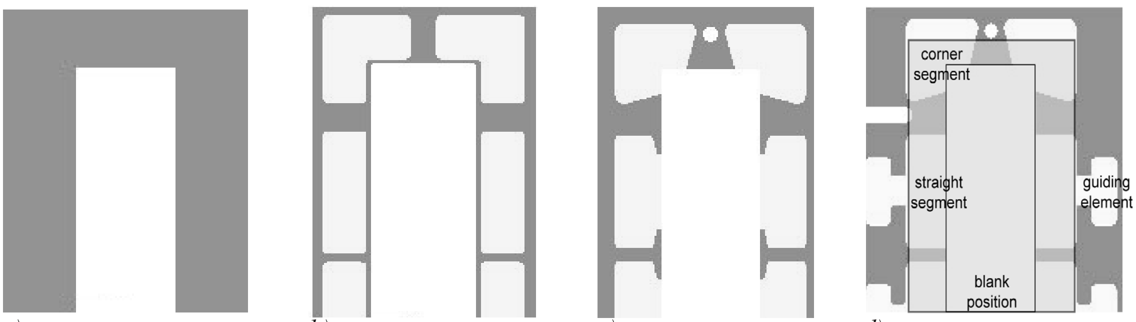
The most significantly controlled parameter was the holding force. The first analyses were made with constant holding force on the blank holder. The holding force was optimized but good parts were still not achieved. Good workpieces are considered to be workpieces without wrinkles, cracks, scratches, and dimensional errors. The critical regions of the workpieces were in the corner areas where radial tensile stresses and tangential compressive stresses are present due to the material's retention property. These compressive stresses often lead to flange wrinkles. Apart from wrinkles, another typical problem in sheet metal stamping is the generation of cracks. Workpieces made by holding forces of less than 400 kN had wrinkles present and those with holding forces of more than 400 kN had cracks present. From Fig. 4 critical areas where wrinkles and fissures occur can be seen.

In order to achieve good parts additional changes had to be made on the computer model. Therefore, segment holding systems were used with distributed holding forces. Optimizing techniques were used for testing the shapes of the segment inserts and the sizes of the local holding forces. Different shapes of segment inserts were numerically calculated and qualities of the workpieces estimated. The shapes of the segments and half of the holding system are shown in Fig 5. All the holding systems consisted of 10 segments



a) *b)* *c)*

Fig. 4. *Critical areas of the workpiece; a) colour scheme, b) wrinkling trend and c) cracks*



a) *b)* *c)* *d)*

Fig. 5. *a) Conventional blankholder and b), c), d) three versions of segmented blankholder*

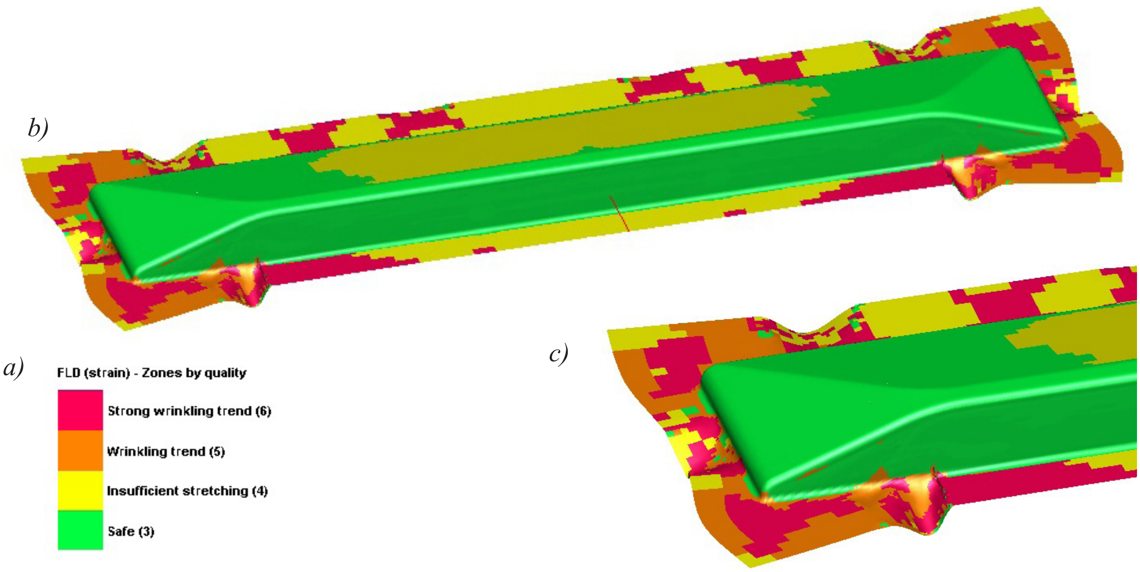


Fig. 6. *Flange wrinkling; a) whole model, b) colour scheme, c) detailed view*

and one guiding blank holder plate, as used for holding in the intermediate areas and for guiding the segment inserts. By using these systems, it is possible to distribute holding forces into 10 areas and each segment's force could be separately controlled.

The results showed that the best segment shape was option d (Fig. 5). The shape of the segments in this case was designed in such a way that the front parts of the straight segments are holding and the rear parts of the segments are guiding. The corner segments did not need an extra guiding. The holding areas in all options were identical.

The results from these computer analyses are shown above. The main problems occurred on those areas shown in Fig. 6. Strong wrinkling tendencies occurred on the areas between the corners and the straight segments.

This flange-wrinkling may have an effect on the end-product, therefore the proposed holding systems did not satisfy primary demands.

In order to solve this problem, the guiding blank holder was also supported by the holding force. The range of this holding force was from 10 to 100 kN. The results proved to be much better and the workpiece already satisfied the presumed demands of good parts. As the results with guiding blank holder forces of both 10 and 100 kN were similar, the guiding blank holder force had a big influence but the value of the force did not. The main reason is that intermediate areas (areas between segments) are relatively small, therefore even a small holding force could decrease wrinkling tendencies in these areas.

Finally, the segmented blankholder forces were optimized. The BH area was divided into ten segments; however this workpiece was symmetrical in one plane and, therefore only 6 segments were actually optimized. The defects were recognized and localized by a human and the desired trajectory of the holding force was adjusted only for those segments situated in that part where tearing or wrinkling occurred. The extent of increasing or decreasing the values of holding forces depended on the sizes of the defects. As mentioned above, optimization was performed using Fuzzy logic rules, which consisted of IF-THEN sentences which were chosen based on the previous results of FEM analysis. Cracks and wrinkles were recognized based on the forming limit diagram.

Table 3. *IF-THEN sentences*

IF	Cracking	THEN	Decrease BHF
IF	Wrinkling	THEN	Increase BHF

Using these rules all 6 segment holding forces were optimized. For determining the rough technological window first the increment of 10 kN was used but later for more précising computing this increment was 1 kN.

Numerous numerical simulations should be performed to obtain the correct trajectories for holding forces. Good workpieces with no wrinkling and no cracks present on the model were made with a holding force from 306 to 734 kN (Fig. 7).

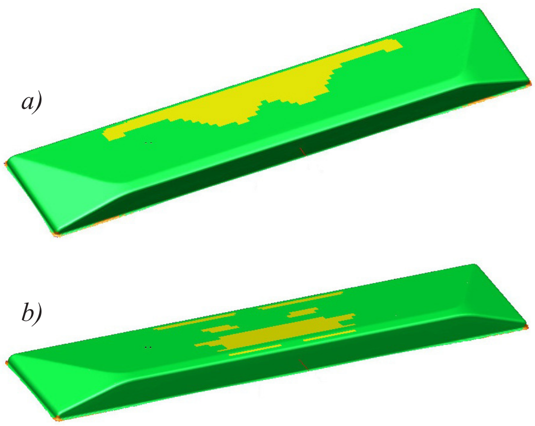


Fig. 7. *Good workpieces made by segmented holding system a) with segmented holding forces 306 kN b) with segmented holding forces 734 kN*

End-workpieces with a drawing-height of 36 mm made by a holding force of less than 306 kN had wrinkles present and workpieces made by a holding force of more than 734 kN had cracks present. The ranges for the holding forces on each segment are shown in Fig. 8.

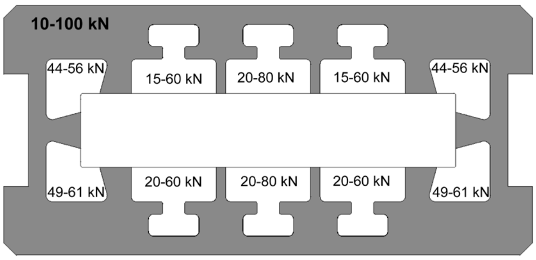


Fig. 8. *Ranges for the holding forces*

A new technological window was constructed and is shown in Fig. 9b. The technological window in Fig. 9a was made with a constant holding force and a conventional holding system with only one holding plate (option a in Fig. 5) and in Fig. 9b was made with a new holding system with segment inserts and with optimized holding forces (option d in Fig. 5). In the technological window with segmented holding force, the holding force is the sum of all 10 segmented forces as well as the blankholder plate force.

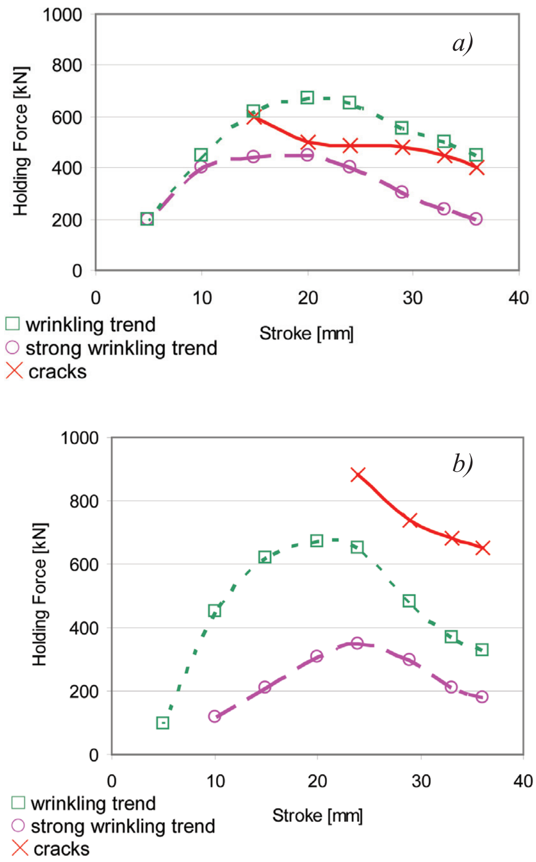


Fig. 9. *Technological window for a) conventional holding system and b) segmented holding system*

The differences in the technological window regarding the corner areas and the straight areas are shown in Fig. 10. From these diagrams it can be seen that the corners areas are more critical than straight areas.

From all diagrams (Figs. 9 and 10) it is clear that the wrinkles in the corner areas had already occurred in the earlier steps of the deep-drawing process. However, later some of the wrinkles disappear which was also confirmed by the experiment (Fig. 11).

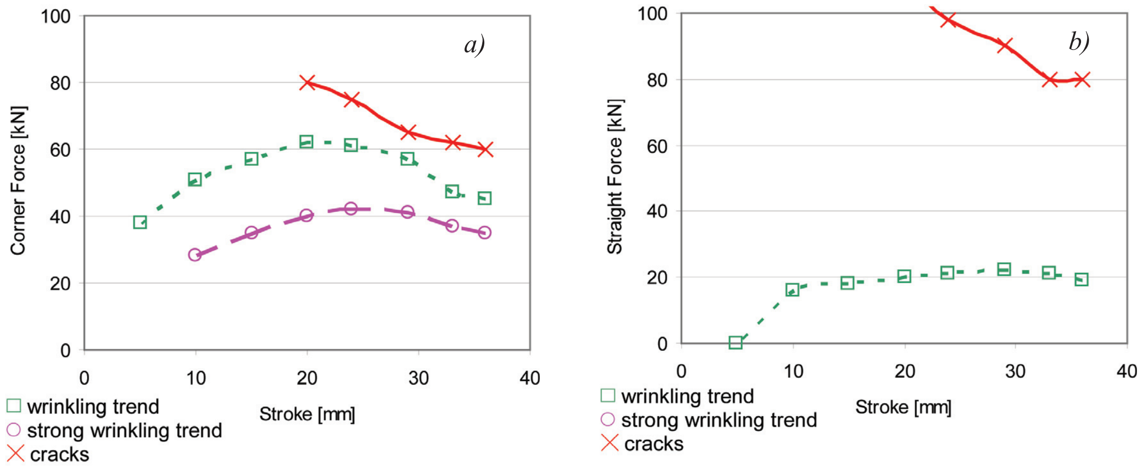


Fig. 10. *Technological window for; a) corner areas and b) straight areas*

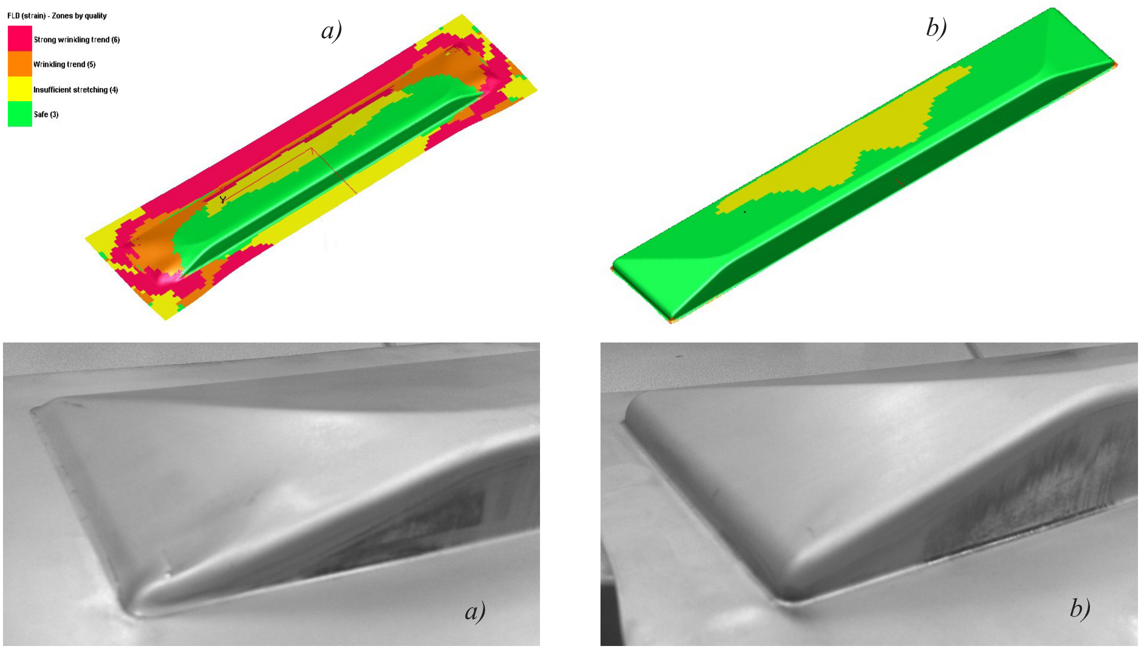


Fig. 11. *Wrinkling trend; a) step 4 (FEM), b) step 10 (FEM), c) early step (experiment) and d) final draw (experiment)*

In order to avoid wrinkling tendencies over all steps time-dependent profiles for corner segmented holding forces will have to be applied, which needs to be carried out in further research.

3 CONCLUSION

Different holding systems were evaluated and the advantages and disadvantages are presented. The presented results for deep drawing show that the quality of a workpiece can be improved with a better holding system. It is evident that even small changes in BHF can lead to failure during the process. These failures can be avoided if a variable BHF is applied, but the correct trajectories need to be chosen. This work shows that the results using guiding blank holder forces of 10 and 100 kN were similar. Therefore, it can be concluded that because of a relatively small area where guiding blank holder force is in contact the blank had a big influence but value of the force did not.

Taking into account the geometric restrictions of the die, the shape of the segment inserts was also highlighted. Finally, the FEM analyses segmented holding forces were optimized. Numerous numerical simulations were performd and technological windows for each area were given.

However, the analyses did not consider spring-back. Spring-back in sheet metal forming can be described as the change in sheet metal shape compared with the shapes of tools after the forming process. Currently, FEM calculations for spring-back are not relevant, therefore further research should be carried out to find out the effects of different holding systems on the spring-back effect during sheet metal stamping processes.

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