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INTRICATE SHAPE STAMPING DRAWING PROCESS SIMULATION WITH THE USE OF DRAW BEADS OR DRAW MOLDING

SIMULACE PROCESU TAŽENÍ VÝTAŽKU NEPRAVIDELNÉHO TVARU S VYUŽITÍM BRZDICÍCH ŽEBER NEBO BRZDICÍ LIŠTY

Abstract

Paper deals with possibilities of draw beads or draw molding utilization in sheet-metal forming of intricate shape stamping. Draw beads appropriate location in process of deep drawing of sheet-metal brings many advantages and it removes a number of unpleasant effects. In paper the analysis of shape, size and suitable location of draw beads in areas where the fastest moving of material exists, is carried out. Suitable versions of draw beads and draw moldings including sizes and location in binder are described.

Deep drawing process simulation of intricate shape stamping was carried out in simulation program Dynaform 5.7. Suitability of draw bead utilization is described on intricate shape stamping drawing from thin deep-drawing steel strip DC04 (11 305.21). The analysis was performed on a blank model created in the BSE (Blank Size Engineering) module for creation of optimal blank in simulation program Dynaform 5.7. For determination of areas suitable for location of draw beads the method using of maximum shear stress trajectories was used. Auxiliary calculations for input values of simulation model were performed in MS Excel programme.

Abstrakt

Článek se zabývá možnostmi použití brzdicích žeber nebo brzdicí lišty při plošném tváření výtažku nepravidelného tvaru. Vhodné umístění brzdicích žeber v procesu hlubokého tažení plechů přináší spoustu výhod a odstraňuje řadu nepříjemných jevů. V článku je proveden rozbor tvaru, velikosti a vhodného umístění brzdicích žeber v oblastech, kde dochází k nejrychlejšímu přemisťování materiálu. Jsou popsány vhodné varianty brzdicích žeber a brzdicích lišt včetně rozměrů a umístění v přidržovači.

Simulace procesu hlubokého tažení výtažku nepravidelného tvaru byla provedena v simulačním programu Dynaform 5.7. Vhodnost použití brzdicího žebra je v článku popsána na výtažku nepravidelného tvaru z tenkého hlubokotažného plechu – pásové oceli DC04 (11 305.21). Analýza byla provedena na modelu přístřihu vytvořeném v modulu BSE (Blank Size Engineering) pro tvorbu optimálního přístřihu v simulačním programu Dynaform 5.7. Pro stanovení oblastí vhodných pro umístění brzdicích žeber byla použita metoda využívající trajektorií maximálních smykových napětí. Pomocné výpočty pro vstupní hodnoty simulačního modelu byly provedeny v programu MS Excel.

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INTRODUCTION

At the production of intricate shape stampings the complicate forming conditions exist, the current presence of different stress in formed material is typical. At drawing of intricate shape stampings the unwanted phenomena can easily arise, such as loss of the plastic deformation process stability. When drawing such intricate stampings the blank area under the binder is often small according to total area of the formed semiproduct. For uniform shaping and stamping rigidity it is necessary to effort the local braking of sheet-metal.

By various technological interventions it is possible to get a different braking intensity which allows the change of the conditions of pulling-in the formed blank sheet-metal into die space. Among the above-listed options the appropriate selection and utilization of draw beads of selected shape, number and method of placement in binder or die area around the stamping. It is possible globally or locally to increase the holding pressure or to increase the area of formed material under binder. The objective of draw bead or draw molding is to prevent the secondary wrinkling of the stamping.

Braking by draw beads belongs to the most effective ways how to control the braking and in needed extend to increase the tensile stress. Acceptable location, geometry and length of draw bead is always a question of many experiments and practical experience.

An important feature of draw beads is the resistance to wear which affects the possibility of galling in sheet-metal drawing. It is necessary to choose the right material of draw bead and proper surface finishing. The usual material for production of draw beads is structural carbon steel E335 (11 600). At non-rotational stampings the draw beads are produced separately and then they are fastened to the milled grooves by pressing, screwing, etc. The choice of geometry and location of the draw bead depends on experience and on the particular stamping.

Utilization of simulation software helps to reduce the preparation time and eliminates the inappropriate decisions on the location of the beads in the forming tool geometry. The sheet-metal forming problems can be solved with the use of the finite element method simulation by software Dynaform 5.7 whose advantage lies in the possibilities of setting up and testing of various shapes, lengths and dimensions of draw beads and their placement in the binder without having to make the expensive prototype of tools.

1 MATERIAL OF INTRICATE SHAPE STAMPING

The initial material for production of intricate shape stamping is strip from steel DC04 (11 305.21), which is supplied in sheets of dimensions (0,9 x 1000 – 2000) mm according to ČSN 42 6312.32. The material is killed, non ageing, with very good properties for deep drawing. During its working the anisotropy of mechanical properties must be taken into account.

Measured and calculated values of the plastics strain ratio r_x in directions of 0°, 45° and 90° towards sheet-metal rolling direction, the values of weighted average of plastic strain ratio, degree of planar anisotropy of plastic strain ratio of strip from steel DC04 (11 305.21) are listed in Tab. 1.

The values of strain hardening exponent n_x in directions of 0°, 45° and 90° towards sheet-metal rolling direction, the strain hardening exponent mean value n_m, the planar anisotropy degree of strain hardening exponent Δn are listed in Tab. 2. These values are used as input when defining the material of blank in the simulation program Dynaform 5.7 in the initial stage of the simulation process of intricate shape stamping drawing.

Tab. 1 Values of the plastics strain ratio r_x in directions of 0°, 45° and 90° towards sheet-metal rolling direction, the values of weighted average of plastic strain ratio, degree of planar anisotropy of plastic strain ratio of strip from steel DC04 (11 305.21).

r_0	r_{45}	r_{90}	$\bar{r}$	Δr
1.95	1.40	2.30	1.76	0.725

Tab. 2 Values of the strain hardening exponent n_x in directions of 0°, 45° and 90° towards sheet-metal rolling direction, the strain hardening exponent mean value n_m, the planar anisotropy degree of strain hardening exponent Δn of strip from steel DC04 (11 305.21).

n_0	n_{45}	n_{90}	n_m	Δn
0.220	0.210	0.210	0.213	0.050

2 DETERMINATION OF BLANK SHAPE AND SIZE

To simulate the drawing process the model of intricate shape stamping with external dimensions of ground (330 × 350) mm and a with height of 105 mm according to design documentation (see Fig. 1) and two models of intricate shape stamping with draw molding (see Fig. 2) which shapes have been modified for location of draw molding around the circumference (see Tab. 6) were constructed. By this the shape change of the model near the die edge was carried out.

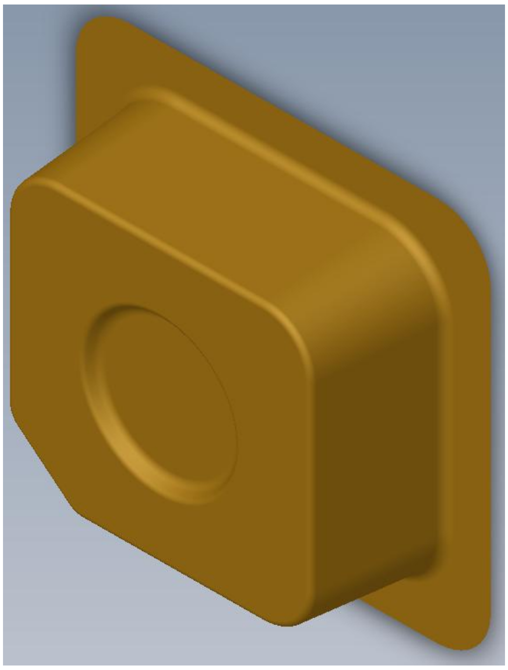

Fig. 1 Model of intricate shape stamping without draw molding.

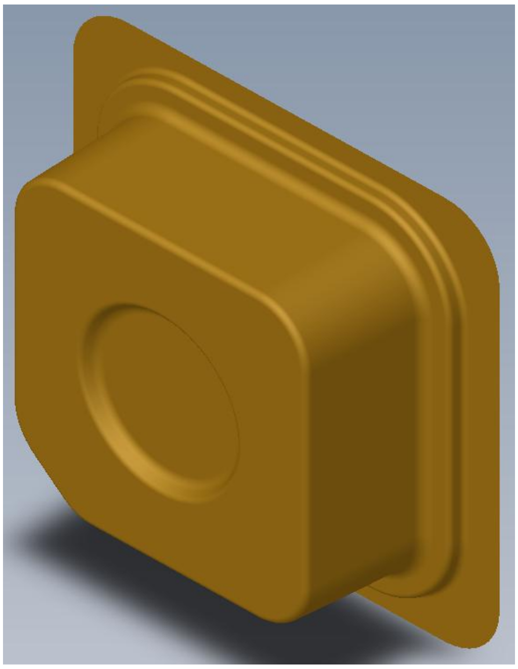

Fig. 2 Model of intricate shape stamping with draw molding.

The models of intricate shape stamping were constructed in the design program Solid Works 2008 in module Surfaces. At modeling the coordinate system where the degree of freedom was chosen in (z)-direction due to the establishment of drawing tools in the simulation program Dynaform 5.7 was maintained. By this method the shell model in *.igs format was developed because in the simulation program Dynaform 5.7 the thickness of the material is specified when defining the material properties. In the program Dynaform 5.7 the optimal blank was developed with the use of the BSE (Blank Size Engineering) module. This module is equipped with one-step M-solver for the rapid assessment of the stamping drawability in the first stage of design of product shape and tool shape where the stamping shape sufficient as input. After generating the blank contour the trimming allowance with the size 10 mm according to ČSN 22 7303.

3 DRAW BEADS

To regulate the material flow during deep-drawing of sheet-metal the draw beads or draw molding are used. Draw beads are used at drawing of stampings with convex bottom, larger nonrotation and intricate shape stampings. The braking by draw beads is among the most effective ways how it is possible to control the braking and in needed range to increase the radial tensile stress while reducing tangential stress. The purpose of the use of draw bead or draw molding is to prevent the secondary wrinkling of stamping walls and the primary wrinkling of the flange. The draw beads are placed in the die or binder of blank to restrict the material flow. Draw molding is placed around the die circumference without interruption, and because it has been placed on the drawing edge, it was filed at described intricate shape stamping among the shape modifications of the stamping. For the most effective draw beads effect it is necessary to find the most suitable geometric profile and dimension of the draw bead. In this case of the simulation of intricate shape stamping drawing was the draw beads in a single row in four selected areas of plane (see Fig. 4) were tested.

Suitable location of draw beads in the binder is always a question of several experiments and measurements. In the technical literature the draw beads distance of 20 mm to 30 mm from the die drawing edge is recommended, in case of more draw beads one after another the distance of 25 mm to 35 mm is kept. An optimal placement of the draw beads is in the flat of the drawing edge contour. Draw beads always have width 5 mm to 10 mm and 1.2 mm to 5 mm high, depending on the size and shape of stamping and on the thickness of drawn sheet-metal (see Fig. 3).

When the choice of geometry of the draw bead (radius, height, etc.) and the location of the draw bead are unsuitable the stamping drawability markedly decreases. The tensile stresses that cause cracking or fracture of sheet-metal near the drawing edge may suddenly increase. Draw bead may not bee too high so that the metal by cold deformation not hardened excessively. High draw bead may cause at indentation to the flat blank the material waviness which consequently can not be removed. It is therefore advantageous to use several low draw beads one after another than one high.

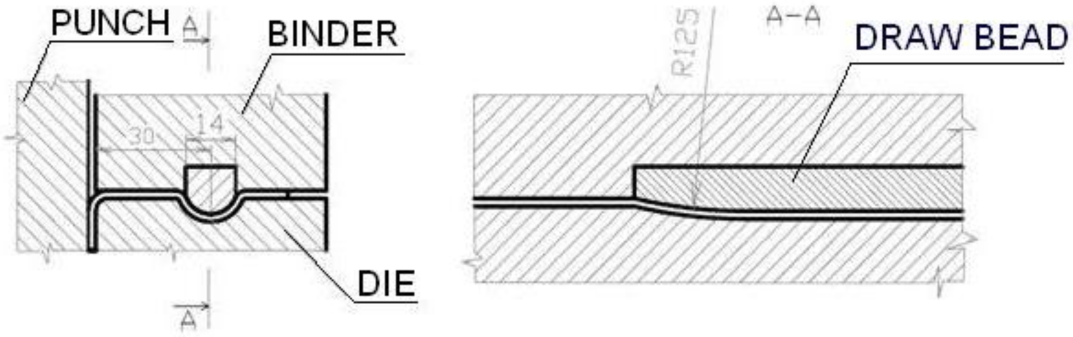

Fig. 3 Example of geometry, location and run of draw bead of semicircular groove shape.

At the deeper drawing for the smooth stamping process is often necessary to use a binder. Binder task is to hold the sheet-metal during the deep drawing process and to prevent waviness. The waviness occurs in the flange (at deep drawing) or in the wall stamping (at stretching). Its purpose is to prevent loss of stability in the stamping flange from the tangential tensile stress due to the drawing. Lack of pressure leads to the flange waviness while the high pressure blocks the stamping and leads to the stamping bottom breaking. For this reason the different types and designs of binders are used.

When using the binder the pressing force can be calculated according to the equation (1) and it should be bigger when the ratio among initial binder width and thickness of the initial blank is larger [5].

The size of the pressing force F_p can be determined by formula:

$$F_p = 0{,}1 \cdot \left(1 - \frac{18 \cdot M \cdot h_0}{(M-1) \cdot 2 \cdot b_0}\right) M^2 \cdot F_{o\,max} \qquad \text{[N]}, \qquad (1)$$

where are b_0 – radius of the initial blank [m], h_0 – blank thickness [m], M – drawing coefficient [–], $F_{o\,max}$ – deformation force at the beginning of the drawing [N].

Deformation force at the beginning of the drawing $F_{o\,max}$ which is necessary to calculate the pressing force F_p in equation (1) can be determined:

$$F_{o\,max} = 2 \cdot \pi \cdot a \cdot h_0 \cdot \sigma_{r\,max} \qquad \text{[N]}, \qquad (2)$$

where are a – stamping finite radius [m], h_0 – blank thickness [m], $\sigma_{r\,max}$ – maximum radial tensile stress [Pa].

4 INTRICATE SHAPE STAMPING DRAWING PROCESS SIMULATION

4.1 Definition of blank and creation of tools for intricate shape stamping in the program Dynaform 5.7

For simulation of the intricate shape stamping drawing process the model of the stamping and the model of the die were constructed in program Solid Works 2008 where the degree of freedom was chosen in the (z)-negative direction. The model of stamping was used for creation of the blank in the program Dynaform 5.7 with the use of BSE (Blank Size Engineering) module. Die model was used for making of tools (Punch, Die, Binder). They had to lay down and follow. All the boundary conditions such as shape and size of the blank, track and the movement of tools, binder force, punch speed, sheet-metal properties and friction coefficient must be determined and respected.

Definition of blank material

Definition of blank was performed for the size of the grid elements („*Radii*") with the parameter „*Radii = 4*" with regard to the size of blank. For the blank the material properties of strip from steel DC04 (11 305.21) with a thickness of 0,9 mm were defined.

Definition of tools and their appointment to the auto position

When defining the tools in the item „*Define Tools*" the separate models were assigned to already preset instruments („*DIE, PUNCH, BINDER*"). The size of elements created by mesh style was chosen 20 due to the size of the stamping.

The punch movement speed is according to recommendation of the technical literature in range between 0,4 ÷ 0,6 m s^{-1}. This speed is suitable for smaller presses. The speed of 0,6 m s^{-1} was chosen.

Tab. 3 Holding forces for blank of intricate shape stamping

Blank	Area of Blank S_i [mm^2]	Effective Area of Binder [mm^2]	Specific Pressure p_p [MPa]	Holding Force F_{p1} [N]
BSE Modul	218,376.2	171,422.8	2.14	360,000

Tab. 4 Holding forces for blank of intricate shape stamping drawed with draw molding

Blank	Area of Blank S_i [mm^2]	Effective Area of Binder [mm^2]	Specific Pressure p_p [MPa]	Holding Force F_{p2} [N]
BSE Modul	218,376.2	167,898.2	2.14	351,000

The binder was made from the model die („*DIE*"). The value of the holding force F_{p1} for intricate shape stamping is in Tab. 3. The Tab. 4 states holding force F_{p2} for intricate shape stamping with a draw molding. Calculations go from equations (1) and (2). Specific pressure of binder ranges p_p = (1.8 ÷ 2.8) MPa as recommended in the technical literature. The pressure of p_p = 2.14 MPa (see Tab. 3 and Tab. 4) was chosen.

Predefined tolls and blank were checked and after setting all of conditions the calculation in the subroutine Dynaform 5.7 – LS-Dyna Jobs Submitter 2.2 was carried out.

4.2 Definition of areas for the location of draw beads at intricate shape stamping drawing

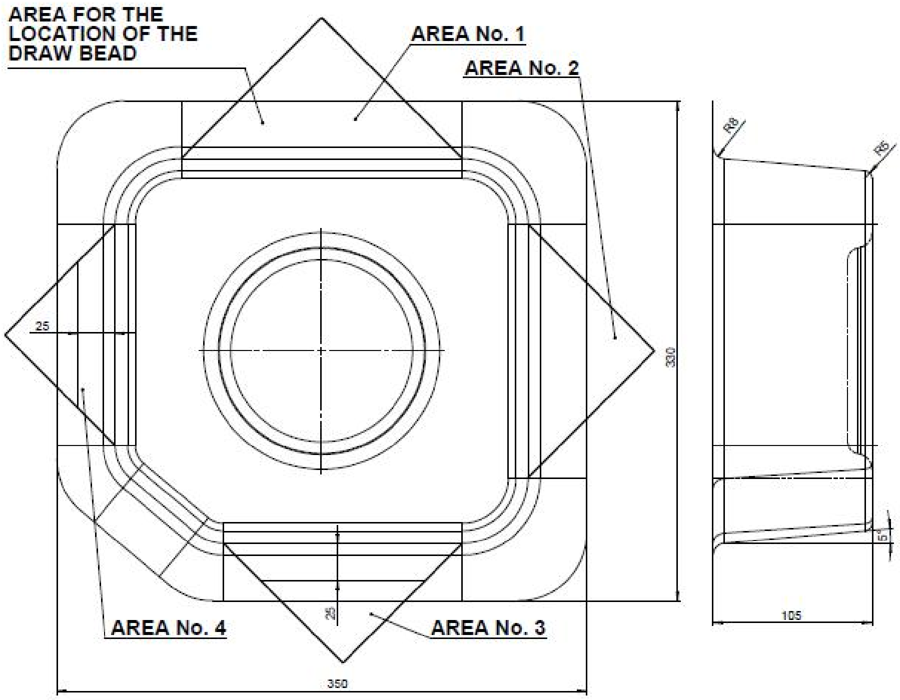

Fig. 4 Suitable areas with triangle shape for the location of the draw beads determined with the use of the method maximum shear stress trajectories.

To determine the effect of draw beads upon the drawing process of intricate shape stamping the authors suggested that the draw beads will be placed in the upper part of the pull toll – binder and will be placed in areas where the material drawing-in is with maximum speed and so it is necessary to brake it. These areas are located in straight line parts of the die drawing edge contour, Fig. 4 shows the triangle contours constructed from the die drawing edge contour reduced for the half sheet-metal thickness using the method of maximum shear stress trajectories. Location of draw bead can be defined as a line which can be located on binder model directly in simulation program Dynaform 5.7. For illustration this line represents the longitudinal axis of the draw bead in a distance of 25 mm from the die drawing edge (see Fig. 4) and the line is located in a designated area No. 3 and area No. 4.

4.3 Intricate shape stamping drawing process simulation from the blank determined by the BSE module with the use of draw beads

On the model of die („*DIE*“), punch („*PUNCH*“) and binder („*BINDER*“) the network of elements (needed for the calculation) was created by meshing method „*Tool Mesh, Connected*“ since the instruments are made only by surfaces. After the above described preparation of a simulation model in the binder the draw beads were defined.

According to the fact that the model of intricate shape stamping with draw molding around the whole circuit was constructed the draw beads of a rectangular and a semicircular shape were chosen. Gradually for the changed geometry parameters of draw beads semicircular and rectangular in shape, especially the draw bead height in range from 2 mm to 4 mm and lengths of draw beads in different areas (see Tab. 5).

Tab. 5 Geometry of the rectangular draw bead chosen for intricate shape stamping drawing process simulation.

Draw Bead Parameters	
„*Depth*“ [mm]	2
„*Entrance Angle 1, 2*“ [°]	55
„*Entrance Radius 1, 2*“ [mm]	6
„*Groove Length*“ [mm]	8
„*Groove Angle 1, 2*“ [°]	55
„*Groove Radius 1, 2*“ [mm]	3

Other parameters („*Miscellaneous Parameters*“) were selected by the program Dynaform 5.7 and because they were satisfactory, they were left unchanged. For the analysis of simulation results the ETA/Post-Proccessor 1.0 was used.

5 RESULTS OF INTRICATE SHAPE STAMPING DEEP-DRAWING PROCESS SIMULATION

5.1 Results of intricate shape stamping drawing simulation without draw beads and draw molding

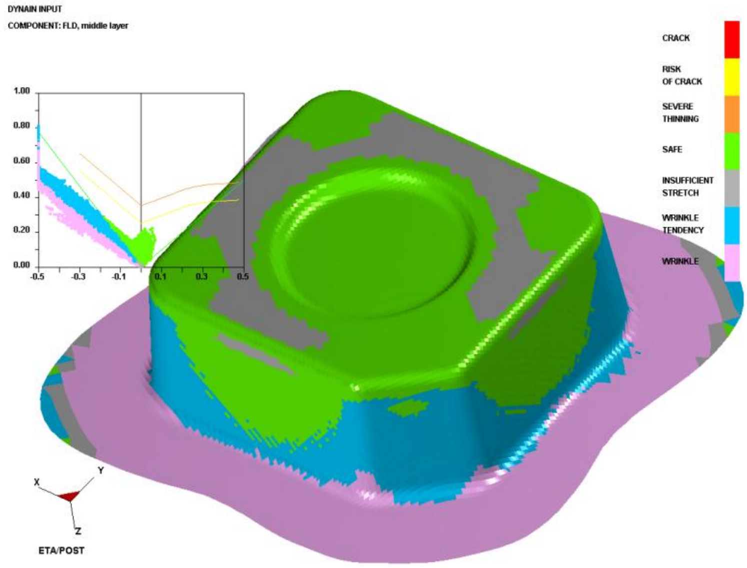

Fig. 5 Analysis of strain with the use of the forming limit diagram „*FLD, True*“ and drawability analysis of intricate shape stamping drawn from steel strip DC04 (11 305.21) without draw beads or draw molding in the drawing process.

Analysis of the intricate shape stamping shown in the forming limit diagram „*FLD, True*“ (see Fig. 5) evaluated the „*True*“ curve of the stress – strain (true strain diagram) where the tendency of wrinkling in the wall of intricate shape stamping – secondary waviness and also the primary waviness at flange surface of intricate shape stamping occurs. On Fig. 5 yellow, lower strain limit curve in the forming limit diagram „*FLD, True*“ shows the boundary of the crack arising, while the allowed deformation at intricate shape stamping are located bellow the curve. For the assessment of the change in the use of plasticity stock due to changes in lengths, geometry, height, location of draw beads of rectangular and semicircular shape in the ETA/Post-Proccessor 1.0 the analysis of the stamping thinning drawn from the optimal blank from steel strip DC04 (11 305.21) (see Fig. 6) was used.

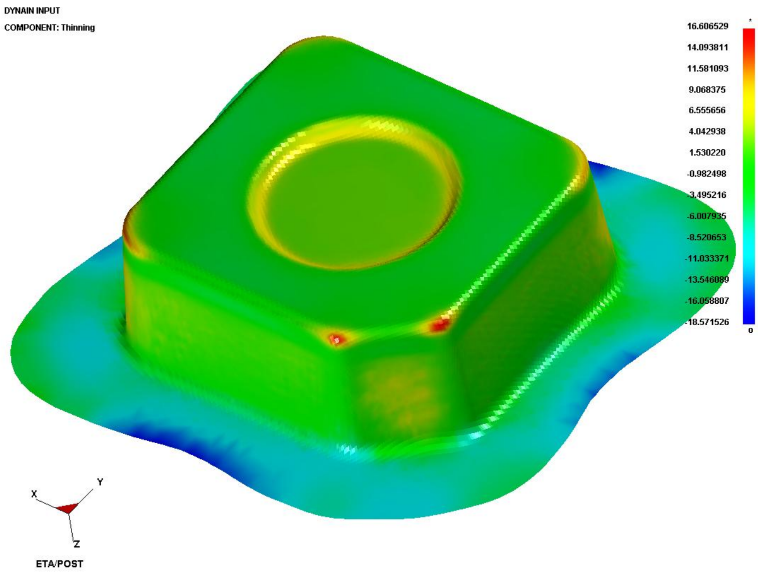

Fig. 6 Analysis of thinning of the wall of intricate shape stamping from steel strip DC04 (11 305.21) without draw molding or draw beads in drawing process

5.2 Results of the intricate shape stamping drawing process with the use of draw molding

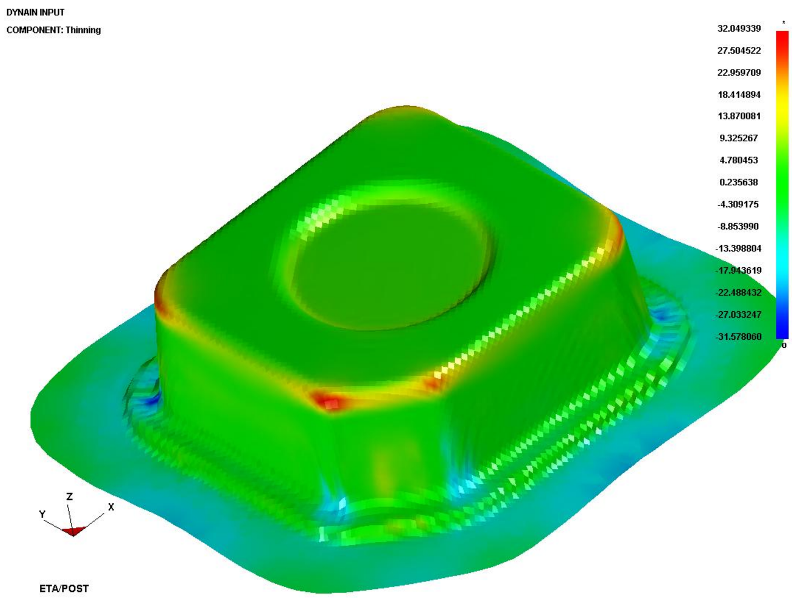

Fig. 7 Analysis of wall thinning at version No. 1 of intricate shape stamping drawn from the optimal blank from steel strip DC04 (11 305.21) with the use of draw molding

Two simulations of drawing of intricate shape stamping with the use draw molding were carried out. The parameters of draw molding are shown in Tab. 6. For the first version of the model of intricate shape stamping with a rectangular draw molding the geometry with the same input and output radius was chosen. At the second model of stamping the adjustment of input and output radius which followed each other continuously was carried out.

Tab. 6 Sizes of draw ledges of intricate shape stamping.

Version No.	Draw molding height [mm]	Draw molding width [mm]	Entrance radius [mm]	Exit radius [mm]
1	12	12	4	4
2	12	12	4	8

From the results of simulation of sheet-metal thinning during the process of drawing of intricate shape stamping results for both versions that the plasticity supply at the stamping bottom runs out and the radial tension significantly increases and thus a thinning of the walls around the circumference the bottom stamping (see Fig. 8). For this reason the drawing of intricate shape stamping with draw molding is inappropriate.

6.2 Results of the intricate shape stamping drawing process with use draw beads

For analysis of using of the draw beads at intricate shape stamping drawing the draw beads of rectangular and semicircular shape were selected. Draw beads were placed on binder. Four sets of calculations were made, first set experimented with geometry of the draw beads, in second set with a length of draw beads in selected areas, in third set with distance from the inner edge of the binder and in fourth set with a draw bead height. Height of draw bead was gradually selected to the size of 2 mm, 3 mm and 4 mm. Example of the draw bead rectangular geometry is in Tab. 7 and the geometry of semicircular draw bead is in Tab. 9. Distance from the inner edge of the die drawing edge was kept after series of simulations on the optimal value 25 mm. Chosen lengths of the draw beads are in Tab. 8.

Tab. 7 Selected options of geometry of the draw beads of rectangular shape to simulate intricate shape stamping drawing.

Draw Bead Parameters	Location of draw beads on binder			
	Draw bead in area No. 1	Draw bead in area No. 2	Draw bead in area No. 3	Draw bead in area No. 4
„*Depth*“ [mm]	2	2	2	2
„*Entrance Angle 1, 2*“ [°]	55	55	55	55
„*Entrance Radius 1, 2*“ [mm]	6	6	6	6
„*Groove Length*“ [mm]	8	8	8	8
„*Groove Radius 1, 2*“ [mm]	3	3	3	3

Tab. 8 The length of the draw beads in different areas.

Binder	Area No. 1	Area No. 2	Area No. 3	Area No. 4
Draw bead length [mm]	139	121	119	99
Short draw beads length [mm]	101	82	60	40

Tab. 9 Selected options for simulation of semi-circular geometry draw beads.

Draw Bead Parameters	Location of draw beads on binder			
	Draw bead in area No. 1	Draw bead in area No. 2	Draw bead in area No. 3	Draw bead in area No. 4
„*Depth*“ [mm]	2	2	2	2
„*Entrance Angle 1, 2*“ [°]	55	55	55	55
„*Entrance Radius 1, 2*“ [mm]	3	3	3	3

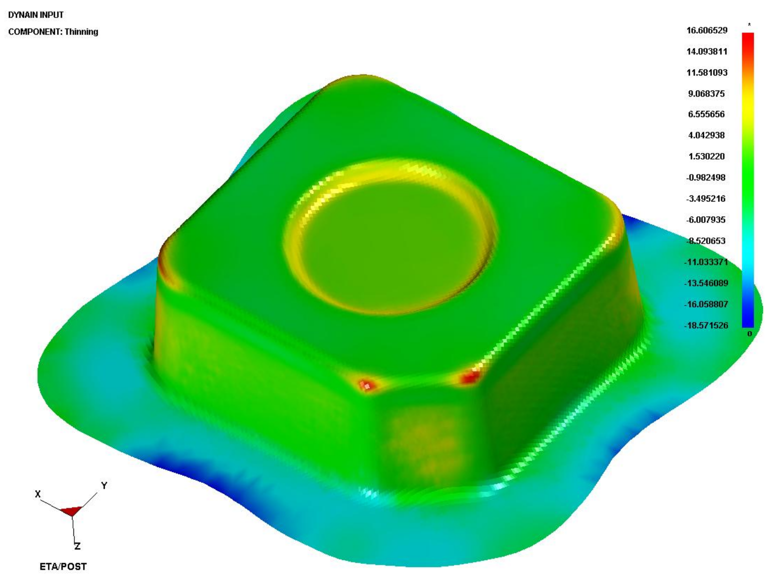

Fig. 8 Analysis of thinning of the wall of intricate shape stamping from steel strip DC04 (11 305.21) with draw beads of rectangular shape in area No. 3 with length of 60 mm and in area No. 4 with draw beads with length of 40 mm.

By analysis of thinning of intricate shape stamping drawn from the optimal blank from steel strip DC04 (11 305.21) it was identified that the most suitable option of position of draw beads is in area No. 3 with a length of 60 mm and in area No. 4 with a length of 40 mm where there is a local effect of draw beads on the corners of the draw beads at the bottom of the intricate shape stamping. The difference between the draw beads of semicircular and rectangular shape was not verified at that intricate shape stamping because almost identical results in the analysis of wall thinning were gained – thinning reaches about 1,5 % and is almost equal to the surface except the bottom and bottom corners. The selected height of draw beads of 2 mm will improve the properties of intricate shape stamping to avoid the tendency to formation of secondary wrinkles in the wall of stamping and a reduction in wrinkles or ripple on the surface of the flange. The selected height of draw beads 3 mm and height of draw beads 4 mm is inappropriate because of the separation of bottom curvature points and walls of intricate shape stamping. Location of draw beads in areas No. 1 and areas No. 2 is not appropriate (see Fig. 4) since the results of simulations of a large retarded the material flow in the process of drawing and arising of crack of the bottom of intricate shape stamping in both forms of draw beads.

7 CONCLUSIONS

By computer simulation of drawing of intricate shape stamping with the use of draw beads with rectangular and semicircular shape when the changes of the radial and tangential stress were observed by analysis of wall thinning of intricate shape stamping, a suitable alternative location of the draw beads to reduce the incidence of secondary wrinkle wall intricate shape stamping was found.

Each variant of forms of draw molding (see 5.2) and draw beads (see 5.3) at the intricate shape stamping led to arising of cracks in the corners of the stamping bottom where the effect of the increased radial stress leads to exhaustion of material plasticity stock. Cracks in the corners near the bottom of the intricate shape stamping are an unacceptable phenomenon. Cracks can be removed by changing the geometry intricate shape stamping, e.g. by increasing the radius of curvature of stamping corners.

From the drawing process simulation of investigated intricate shape stamping is seen that the most appropriate way of drawing is way without draw beads or draw molding because there is no arising of cracks in the corners near the stamping bottom. Any primary waviness on the flange surface can be removed by trimming of the intricate shape stamping edge.

In the case of undesirable secondary waviness in the walls of intricate shape stamping the drawing with draw beads could be used but it would be necessary to adjust the stamping shape that in the corners at the bottom to avoid the exhaustion of material plasticity stock.

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