MM Science Journal | www.mmscience.eu
ISSN 1803-1269 (Print) | ISSN 1805-0476 (On-line)
Special Issue | VRBA100
International Conference on Modern Manufacturing Technologies
4. 10. 2023, Ostrava, Czech Republic
DOI: 10.17973/MMSJ.2024_02_2023138

VRBA2024-00004

BLANK MATERIAL INFLUENCE ON STAMPING SPRINGBACK

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Abstract

This paper concerns the evaluation of blank material influence on springback of irregularly shaped stamping after drawing operation to keep the dimensions and tolerances of stamping after the drawing process which are given in part drawing. Simulation of the drawing process and consequent stamping springback were carried out by PAM-STAMP 2G™ software which uses the finite elements method, with the use of blanks from strip steels DX54D, HC220P, HX220BD and HX220YD. Two mesh strategies for drawing tool parts in the software PAM-STAMP 2G™ were compared. Stamping springback was evaluated with the use of a reference points system. Critical areas of deformations and stamping springback were evaluated. Simulation results were compared with measurements on real stampings. The most suitable strip steel in terms of achieving the minimum size of springback after stamping drawing was evaluated.

Keywords:

Drawing, finite elements method, sheet-metal, simulation, springback, 3D measuring device

1 INTRODUCTION

Also known as sheet metal stamping or sheet metal forming, sheet metal forming technology has multiple applications in manufacturing due to its minimal waste and low production costs, especially in the mass production of shape-matching parts, but only under the assumption of low scrap in the press shops. The causes of rejects are often insufficient technological efficiency of the produced parts, exceeding the formability limits of the material, incorrectly chosen shapes of the blanks or springback of the stampings after drawing.

For the production of deep or shape-complex stampings, it is necessary to choose deep-drawing steel with good formability [Cada 1997, Evin 2012, Zaba 2012, Novak 2019, Zaba 2023], which can be expressed by forming limit diagrams [Cada 1996]. Since formed components are usually subsequently joined into larger units, another important material property is its weldability and post-weld properties in the heat-affected zone [Sternadelova 2019]. The most commonly used material in the Czech Republic is the DC04 calmed steel, which is produced by continuous casting [Velicka 2013]. In cases where higher load resistance is required, materials with higher yield strength values can be used [Narayanasamy 2008, Evin 2012]. For some applications, the mechanical properties of sheet metal can be increased, e.g., by the unconventional forming method DRECE (Dual Rolls Equal Channel Extrusion) [Rusz 2019, Hilser 2020, Rusz 2020, Jablonska 2021, Pastrnak 2021]. When it is necessary to produce spare parts for which the type of their material is not known, their material analysis can be performed [Kudrna 2020]. Materials have different deformation capabilities and different values of springback.

Springback is an unwanted additional deformation of the stamping, which is caused by the release of stress after the stamping is pulled out of the forming tool. In sheet metal forming, geometric defects include angular changes in the walls, rotation of the side walls, rotation of the blank, edge deformation, surface curvature and overall shape change. The size of the springback after pressing can cause the prescribed tolerances on the part drawing not to be met. The size of the springback is mainly influenced by the amount of elastic deformation, the type of material, and the geometry of the pressing [Shao 2013]. The geometry of the part should be designed so that the size of the springback is as insensitive as possible to changes in material type, thickness, and pressing parameters.

When designing a drawing tool, it is advisable to verify its functionality by simulating the drawing process before manufacturing. It is necessary to design a suitable blank shape, dimensions and material of the blank and to verify the suitability of the designed shape of the components for the sheet metal drawing production method [Cada 2021, Cada 2022, Cada 2023].

When tuning tool dimensions for the production of complex shaped stampings with full dimensions and tolerances on the production drawing, it is necessary to evaluate the shape deviations arising after drawing and after subsequent springback [Ito 2007]. The simulation of the springback is usually performed as a supplementary calculation after the simulation of the drawing process.

Minimizing the springback of the stamping can be achieved by the appropriate choice of the material of the blank, a greater degree of deformation of the stamping surfaces or by modifying the drawing tool so that the given surface or edge after springback corresponds to the required tolerances specified in the drawing of the part [Nowosielski 2013, Pacak 2016, Pacak 2017, Pacak 2019]. The method of deformation networks can be used to analyze the material flow in the drawing process [Cada 2003, Otzurk 2009].

The lifetime of forming tools is affected by their wear resistance [Evin 2019, Tavodova 2020]. Prevention of defects in forming tools is possible by using non-destructive detection methods [Stancekova 2013]. Residual stresses after forming can be analyzed using Barkhausen noise [Neslusan 2011].

A well-designed maintenance organisation [Necas 2019, Necas 2021, Schindlerova 2021] and fault monitoring and prevention [Sproch 2021] are important in the production process as they significantly affect the efficiency, reliability and safety of production. Achieving maximum production productivity and eliminating waste can be achieved, for example, by using the Value Stream Mapping Method [Sajdlerova 2015], which is part of Lean Management, as well as by appropriate design of the distribution warehouse [Schindlerova 2019].

Since the springback of the stamping after the drawing is significantly influenced by the material of the blank, this paper focuses on the determination of the influence of the blank material on the amount of springback of an irregularly shaped stamping. The aim of the analyses of the drawing of irregularly shaped stampings from the four alternatives of the blank material was to compare the drawing results with each other and to select a suitable blank material for the drawing of the irregularly shaped stamping, which allows achieving the minimum deviation from the shape prescribed on the drawing of the component after the drawing is completed and the subsequent springback of the stamping.

1.1 Stamping Characteristic

For evaluation of blank material influence on stamping springback the irregularly shaped stamping at which the springback considerably influences the final shape after drawing was chosen (Fig. 1).

Fig. 1: Irregularly shaped stamping chosen for the evaluation of blank material influence on stamping springback

In the stamping drawing the tolerance of dimensions of the bottom flat flange side is prescribed ±0.5 mm, the tolerance of dimensions of other stamping places is prescribed ±0.8 mm and the stamping surface is determined as +Z200 that ranges in thickness interval (10–20) μm. The zinc surface finish layer density was 7.1 g cm^{-3}.

1.2 Materials

For chosen irregularly shaped stamping (see 1.1) a suitable material, which fulfils all requirements in stamping drawing and which enables to minimize the size of springback after drawing, was necessary to be chosen. For the production of the given stamping in progressive drawing tool the coils with dimensions of (0.65 x 600) mm according to EN 10268 that correspond to EN 10346 were determined.

For testing and reciprocal comparison four different strip steels with the same thickness of 0.65 mm were chosen – continuously hot-dip coated flat steels DX54D, HX220BD and HX220YD according to EN 10346 and the steel with high yield strength, cold rolled, intended for cold forming – HC220P according to EN 10268.

Strip steel HX220BD is a type of bake hardening steel (specification B in steel mark). These steel types have defined an increase in the contractual yield point after heat treatment.

Strip steel HX220YD is a type of IF steel without intercrystalline elements with high strength (specification Y in steel mark). IF steels are made with controlled composition to achieve better values of the plastic strain ratio r_α and the strain hardening exponent n_α.

Mechanical properties of tested strips from steels DX54D, HC220P, HX220BD and HX220YD are in Tab. 1. The values of the plastic strain ratio r_α in directions of 0°, 45° and 90° towards sheet-metal rolling direction, the values of the weighted average of plastic strain ratio $\bar{r}$, degree of planar anisotropy of plastic strain ratio Δr of strip steels are in Tab. 2. The values of the strain hardening exponent n_α 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 steels are in Tab. 3.

Table 1: Mechanical properties of strips from cold rolled steels DX54D, HX220BD and HX220YD according to EN 10346 and HC220P according to EN 10268

Mark of steel	Numeric marking	Surface finishing	R_e (MPa)	R_m (MPa)	A_{80} (%)	$r_{90\,min.}$ (–)	$n_{90\,min.}$ (–)
DX54D	1.0306	+Z200	120–220	260–350	34	1.4	0.18
HC220P	1.0397	+Z200	220–270	320–340	32	1.3	0.16
HX220BD	1.0919	+Z200	220–280	340–420	32	1.2	0.15
HX220YD	1.0923	+Z200	220–280	340–420	32	1.5	0.17

Table 2. Values of the plastic strain ratio r_α in directions of 0°, 45° and 90° towards sheet-metal rolling direction, the values of the weighted average of plastic strain ratio $\bar{r}$, degree of planar anisotropy of plastic strain ratio Δr of strip steels DX54D, HC220P, HX220BD and HX220YD

Mark of steel	r_0 (–)	r_{45} (–)	r_{90} (–)	$\bar{r}$ (–)	Δr (–)
DX54D	2.22	1.82	2.60	2.12	0.59
HC220P	1.75	1.05	2.14	1.50	0.90
HX220BD	0.98	0.92	1.30	1.03	0.21
HX220YD	1.41	1.35	1.72	1.46	0.22

Table 3. Values of the strain hardening exponent n_α 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 steels DX54D, HC220P, HX220BD and HX220YD

Mark of steel	n_0 (–)	n_{45} (–)	n_{90} (–)	n_m (–)	Δn (–)
DX54D	0.19	0.23	0.22	0.21	-0.03
HC220P	0.24	0.23	0.23	0.23	0.00
HX220BD	0.16	0.15	0.18	0.16	0.02
HX220YD	0.19	0.17	0.20	0.18	0.03

2 METHODS

For the analysis of the size of springback of irregularly shaped stamping (see 1.1) drawn from blanks made from strip steels DX54D, HC220P, HX220BD and HX220YD (see 1.2) the numerical simulations and experiments were carried out.

The numerical simulations of stamping drawing and subsequent springback (see 2.1) were carried out by PAM-STAMP 2G™ software which uses the finite elements method. Two mesh strategies for drawing tool parts in PAM-STAMP 2G™ software for monitoring springback after drawing process simulation were compared.

The experiments (see 2.2) concern drawing of stampings from blanks made from four tested strip steels (see 1.2) by the hydraulic transfer press Schuler T2-250–10-400 and subsequently measurement of stampings dimensions by the portal 3D coordinate measuring machine WENZEL LH 87.

2.1 Numerical Simulations

The evaluation of various blank materials' influence on drawability, utilization of stock plasticity, sheet-metal thinning, wave occurrence and subsequently the size of springback after the drawing process of chosen stamping (see 1.1) was carried out by the numerical simulations.

The numerical simulations of stamping drawing and subsequent springback were carried out by PAM-STAMP 2G™ software which uses the finite elements method. The simulation model of the drawing process included three stages – the stage of blank holding *“Holding“*, the stage of stamping drawing *“Stamping“* and the final stage of stamping springback after drawing *“Springback“*.

Creation of Models

An initial 3D model of the irregularly shaped stamping was created in the coordinate system that corresponded to the location of the specified part at the car bodyshell. For this reason, it was necessary to centre the model of the die to the global coordinate system that is the basis for the drawing process simulation in PAM-STAMP 2G™ software. A negative z-axis direction was chosen as the drawing direction in the global coordinate system.

Three points of the reference points system (RPS) for measurement of dimensional deviations from the nominal shape determined by part drawing were determined as shown in Fig. 2. The RPS is used for the same establishment of the stamping to the measuring system and simultaneously defines the measurement base from which the other dimensions are measured. Three determined points of the RPS were entered into springback simulation and they were also later used for measurement of real stamping dimensions by portal 3D coordinate measuring machine WENZEL LH 87 (see 2.2).

From the 3D model of the irregularly shaped stamping the model of the die and then the model of the punch were created. After that, the model of the blankholder was created from the model of the die.

The blank network was generated together with boundary, contact and burdening conditions for stamping in the environment of the graphic pre-processor. Concerning the size of the blank the size of the grid was set to the value of *"Mesh Size = 4"*.

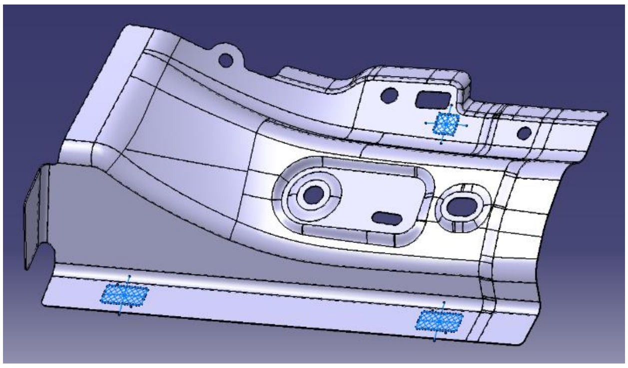

Fig. 2:. Model of irregularly shaped stamping with three marked points of the RPS (three blue cross-hatch rectangles) and defined positions of holes in the component

Choice of Mesh Strategies for Tool Parts

For the deep-drawing process simulation of irregularly shaped stamping was necessary to choose an appropriate mesh strategy. For assessment of the springback size according to the rules for setting calculation with springback the mesh strategies *"Springback"* and *"Compensation"* for creation of elements on tools were chosen.

The general rule for surface discretization into finite elements mesh generated by mesh strategy is that radii on drawing tool parts must be described by a sufficient number of elements. At meshing of tool parts for springback calculation, the value of the maximum angle between adjacent elements is recommended at 7.5° [MECAS ESI 2020]. At blank the maximum element size in the mentioned two mesh strategies is recommended of 10 mm. Both chosen mesh strategies have default values of maximum angle between adjacent elements of 7.5°. The maximum element size of tool parts in mesh strategy *"Springback"* is set to 30 mm (for an approximate calculation) and in mesh strategy *"Compensation"* the maximum element size of tool parts is set to 10 mm (for a more accurate calculation).

Input of Blank Materials

Hill's formulation of the plasticity condition (Hill 1948) is the basis for the description of the material behaviour. Therefore, when defining the material properties, the menu *"Orthotropic Hill 48"* was used where the blank material properties were entered. The required values of the properties of blanks from strip steels DX54D, HC220P, HX220BD and HX220YD, which are necessary for drawing process simulation, were taken from Tabs. 1–3. The material properties from the material database of the program PAM-STAMP 2G™ were also defined.

Setting of Drawing Conditions

Concerning real conditions at the drawing of irregularly shaped stamping the parameters of the drawing were set up: the holding force of F_p = 80 000 N, the blankholder specific pressure of p_p = 2.6 MPa and the punch movement speed of 0.4 ms^{-1}. Because the clearance between punch and die must be secured at the drawing tool, the clearance of 10 % of sheet-metal thickness, i.e. 0.65 mm (see 1.2), was set up, so the value *"Contact gap"* of 0.065 mm. As the condition for the blankholder, the height of the vertical wall of 10 mm was set up. This size was sufficient to run the drawing process simulation correctly.

In all stages of the simulation, i.e. *"Holding"*, *"Stamping"* and *"Springback"*, the type of contact *"Accurate"* between separate tool parts was used.

Setting of Calculation

For each stage of the drawing process simulation, i.e. *"Holding"*, *"Stamping"* and *"Springback"*, the function *"Multi-host"* was used due to the requirement of different types of solvers in these operations. The function allows for separate operations to set the different types of solvers before starting of simulation which shortens the time of calculation.

The solver type of *"SMP-SP"* (Shared Memory Process – Single Precision) was chosen for the stage of blank holding *"Holding"* and the stage of stamping drawing *"Stamping"* with the calculation *"Explicit"*.

For accurate calculations of springback size in drawing process simulation the macro *"DoubleAction.ksa"*, was chosen.

The solver type of *"SMP-DP"* (Shared Memory Process – Double Precision) was chosen for the stage of stamping springback *"Springback"* for the calculation of *"Advanced Implicit"*. This method of double-precision calculation is more demanding on computational time [ESI Group 2023].

For the calculation of springback at stamping the type of calculation *"Advanced Implicit"*, with adaptive automatic meshing *"Automatic Refinement: Sliding Radius = 4"*, was chosen. This is the size of the smallest measured value of the radius on stamping from the point of view of adaptive meshing. The condition that the deformed element size must be less than 25 % of the total size of the drawing radius and half of the sheet-metal thickness must be fulfilled [ESI Group 2023].

For standard calculation of drawing process simulation, equation (1) is valid:

$$d \le 0.50 \cdot (R_{\min} + 0.5 \cdot t) \qquad (1)$$

For springback calculation, equation (2) is valid:

$$d \le 0.25 \cdot (R_{\min} + 0.5 \cdot t) \qquad (2)$$

where are: *d* (mm) stamping finite radius, R_{min} (mm) minimum bending radius, *t* (mm) material thickness.

2.2 Experiments

Drawing of stampings from blanks made from four tested strip steels (see 1.2) was carried out at the hydraulic transfer press Schuler T2-250–10-400.

Measurement of stamping dimensions was carried out by the portal 3D coordinate measuring machine WENZEL LH 87 (made in Germany) in the air-conditioned room. At this machine the measuring range in axes x/y/z is (800 x 1000 x 700) mm, Maximum Permissible Error for length measurement is MPE_e = 2.5 + (L/300) µm. For the measurement of stamping dimensions, the Renishaw Swivel Head PH10M with the Measuring Probe Renishaw TP20 (Maximum Permissible Error of Probe MPE_p = 3.0 µm) were used.

The measurement included the elaboration of a measurement protocol by measuring machine software Metromec CM 3.90. The measurements were related both to the values prescribed by the classic drawing and to the model that was created and stored in the form of a 3D electronic file.

3 RESULTS

3.1 Results of the Simulations

The stamping drawability analysis (Fig. 3) shows deformations of irregularly shaped stamping (see 1.1) with the estimated size and the occurrence of wrinkling. Effort is to achieve the highest possible degree of stamping material deformation with fulfilling low risk of failure, low thinning of the sheet metal and the non-occurrence of wrinkling. A deformed stamping edge is less likely to springback from stamping.

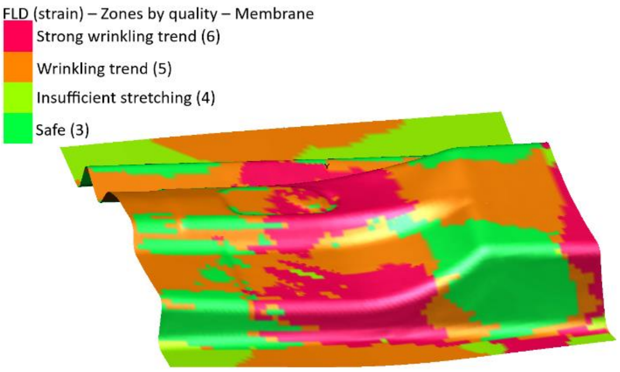

Fig. 3: Drawability analysis of irregularly shaped stamping using blank from strip steel HC220P with chosen mesh strategy "Compensation" for drawing tool parts

When using compared materials DX54D, HC220P, HX220BD and HX220YD the wrinkling of the stamping arises due to local material thickening. The secondary wrinkling in this case occurs at the lower stamping stroke and in the side wall of the stamping where the influence of tangential stress occurs in the thickening of the material.

Drawability analysis of stamping with the use of forming limit diagram is shown in Fig. 4 where all evaluated states of strain detected at stamping lie in a safe area in terms of the risk of crack in stamping. The forming limit diagram of the given sheet metal shows the maximum and minimum deviations of thickening from safe strain. The largest deviations from safe strain can be seen in areas of material where pressing (*"Wrinkling Trend"* – orange area) and thickening (*"Strong Wrinkling Trend"*) – purple area of material exists. These critical areas were assessed when evaluating the results of simulation and tuning of real results. Furthermore no-deformed area *"Insufficient stretching"* and safe area *"Safe"* form a minority share of the total stamping area.

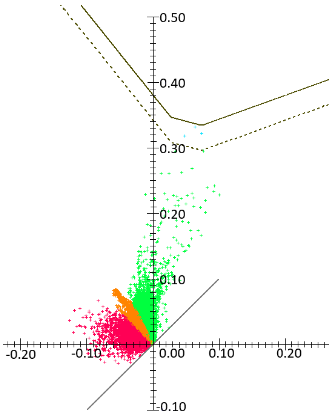

Fig. 4: Forming limit diagram with limit strain curve of irregularly shaped stamping using blank from strip steel HX220BD with chosen mesh strategy "Springback" for drawing tool parts

Analysis of fracture risk of stamping (Fig. 4) is given by numeric value that represents the highest use of plasticity stock at the given site of stamping. If the result reaches the value of 1, it means that the deformation lies on the limit deformation curve in the forming limit diagram and the limit state that is tensile strength or local thinning or failure of sheet metal is reached.

The sheet-metal thinning analysis (Fig. 5) informs about the percentage the sheet metal during the drawing of stamping thinned or thickened. The thinning of material in the range of 25 % to 30 % is the limit value needed for the review process of drawing, thinning of material above 30 % is quite inconvenient. In Fig. 5 is seen that for blank from strip steel HX220YD the thinning of material did not exceed 25 %. Similar results were achieved with other tested materials (see 1.2).

A comparison of thickness analysis results of stamping wall in critical areas for materials DX54D, HC220P, HX220BD and HX220YD with selected mesh strategies "Springback" and "Compensation" is seen in Tab. 4.

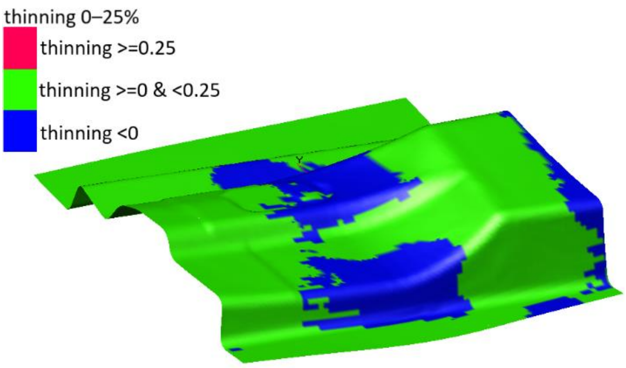

Fig. 5: Thinning analysis of irregularly shaped stamping using blank from strip steel HX220YD with chosen mesh strategy "Compensation" for drawing tool parts

Table 4. Comparison of thickness analysis results of stamping wall of internal reinforcement of car bodyshell B-pillar using blanks from strip steels DX54D, HC220P, HX220BD and HX220YD

Mark of steel	Mesh strategy „Springback"		Mesh strategy „Compensation"	
	Min. thickness (mm)	Max. thickness (mm)	Min. thickness (mm)	Max. thickness (mm)
DX54D	0.540	0.679	0.457	0.725
HC220P	0.505	0.702	0.514	0.719
HX220BD	0.452	0.721	0.449	0.736
HX220YD	0.485	0.702	0.490	0.708

3.2 Results of the Experiments

On the 3D measuring device, Wenzel the dimensional measurement using RPS points of irregularly shaped stamping at the control product was performed. The results of measurement show measured points and edges on stamping and their dimensional values. These values show deviations from the actual dimensions. Values, that meet the prescribed tolerance, are marked in green colour (Fig. 6), yellow colour marked values are marginal. Off-size values that are over the border prescribed values on the production drawing are marked in red colour.

4 DISCUSSION

4.1 Comparison of Irregularly Shaped Stamping Geometries Made from Various Materials with the Part Drawing

The axes perpendicular to the flat surface of stamping are marked by index T. For evaluation of springback size for both mesh strategies *"Springback"* and *"Compensation"* a total of 20 section planes of 14.24 mm distance from each other according to the overall dimensions of the stamping (Fig. 7).

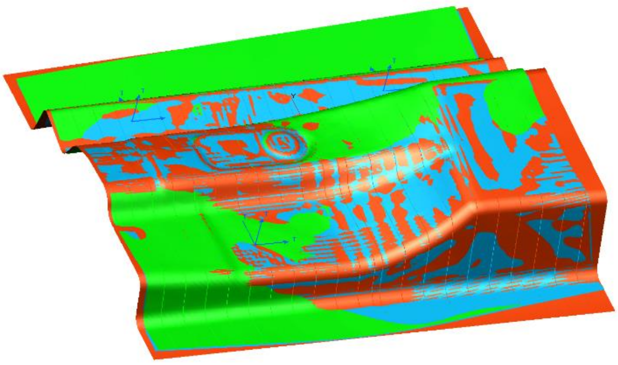

Fig. 7: Comparison of the nominal geometry shape (shown red) with states of stamping geometry before springback (shown blue) and geometry after springback (shown green) of irregularly shaped stamping using blank from strip steel HC220P with chosen mesh strategy "Compensation" for drawing tool parts

The planes were chosen in a global coordinate system perpendicular to the x-axis because of the angular tracking changes between stamping and the forming tool after deformation force unloading. The rotation of side walls that represents a curved incurred as the result of sheet-metal drawing over median radius, the curvature of the surface and overall shape change were also observed.

The nominal geometry of stamping without shape deviations according to part drawing with shearing allowance was imported to the comparison of separate states of springback that is shown by red colour in Fig. 7. Furthermore, for comparison of springback size the resulting geometry of stamping without springback was imported from the stage of drawing process simulations (shown in blue colour). The resulting stamping geometry after springback is shown in green colour.

4.2 Comparison of Springback Simulation Results with the Stamping Measurement Results

For the section sloping plane on the part drawing the tolerance of 0.5 mm is specified where the RPS points are entered, i.e. points of RPS 2 and RPS 3 (Figs. 5 and 7). In other parts of the stamping, the tolerance of 0.8 mm is determined. Comparing planes in selected sections before springback after drawing process simulation for both mesh strategies *"Springback"* and *"Compensation"* without shape deviations the geometric deviations of outline contours from the outline contour of nominal stamping geometry ranged to 0.18 mm. This measured deviation maximum value was found when using a blank made from strip steel HX220BD and because of tolerances on the part drawing and also concerning measured deviations resulting springback geometry shape of stamping is negligible.

4*Lo-tol 3*Lo-tol 2*Lo-tol Lo-tol 50%Lo-tol Nominal Nominal 50%Hi-tol Hi-tol 2*Hi-tol 3*Hi-tol 4*Hi-tol

EDGE24	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	0.27	0.00	0.27	0.50	-0.50
X-axis	1954.81	1954.53	0.27	0.50	-0.50
Y-axis	-679.93	-679.85	-0.08	0.50	-0.50
Z-axis	636.88	636.85	0.03	0.50	-0.50

EDGE25	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	0.42	0.00	0.42	0.50	-0.50
X-axis	1953.22	1952.80	0.42	0.50	-0.50
Y-axis	-694.68	-694.77	0.10	0.50	-0.50
Z-axis	652.08	652.10	-0.03	0.50	-0.50

EDGE26	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	0.30	0.00	0.30	0.50	-0.50
X-axis	1950.85	1950.54	0.31	0.50	-0.50
Y-axis	-685.31	-684.95	-0.36	0.50	-0.50
Z-axis	668.51	668.49	0.01	0.50	-0.50

EDGE29	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	0.27	0.00	0.27	0.50	-0.50
X-axis	1945.28	1945.02	0.26	0.50	-0.50
Y-axis	-707.91	-708.26	0.35	0.50	-0.50
Z-axis	730.62	730.67	-0.04	0.50	-0.50

EDGE30	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	0.00	0.00	0.00	0.50	-0.50
X-axis	1934.92	1934.94	-0.01	0.50	-0.50
Y-axis	-705.61	-706.22	0.61	0.50	-0.50
Z-axis	741.31	741.44	-0.13	0.50	-0.50

EDGE28	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	0.17	0.00	0.17	0.50	-0.50
X-axis	1946.64	1946.47	0.17	0.50	-0.50
Y-axis	-695.09	-695.04	-0.04	0.50	-0.50
Z-axis	710.90	710.94	-0.04	0.50	-0.50

EDGE31	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	0.01	0.00	0.01	0.50	-0.50
X-axis	1875.67	1875.67	-0.00	0.50	-0.50
Y-axis	-708.07	-708.02	-0.05	0.50	-0.50
Z-axis	739.20	739.18	0.02	0.50	-0.50

EDGE27	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	0.06	0.00	0.06	0.50	-0.50
X-axis	1948.36	1948.27	0.09	0.50	-0.50
Y-axis	-687.05	-686.57	-0.48	0.50	-0.50
Z-axis	690.46	690.55	-0.09	0.50	-0.50

EDGE32	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	0.13	0.00	0.13	0.50	-0.50
X-axis	1820.26	1820.27	-0.01	0.50	-0.50
Y-axis	-709.55	-709.57	0.03	0.50	-0.50
Z-axis	737.15	737.02	0.13	0.50	-0.50

EDGE33	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	-0.01	0.00	-0.01	0.50	-0.50
X-axis	1760.69	1760.69	-0.00	0.50	-0.50
Y-axis	-711.08	-711.11	0.03	0.50	-0.50
Z-axis	734.63	734.65	-0.02	0.50	-0.50

EDGE34	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	-0.20	0.00	-0.20	0.50	-0.50
X-axis	1711.49	1711.48	0.01	0.50	-0.50
Y-axis	-712.22	-712.28	0.06	0.50	-0.50
Z-axis	732.44	732.65	-0.21	0.50	-0.50

EDGE35	Actual	Nominal	Difference	Hi-tol	Lo-tol
Point-Profile	0.04	0.00	0.04	0.50	-0.50
X-axis	1704.27	1704.31	-0.04	0.50	-0.50
Y-axis	-714.49	-714.31	-0.18	0.50	-0.50
Z-axis	723.39	723.35	0.04	0.50	-0.50

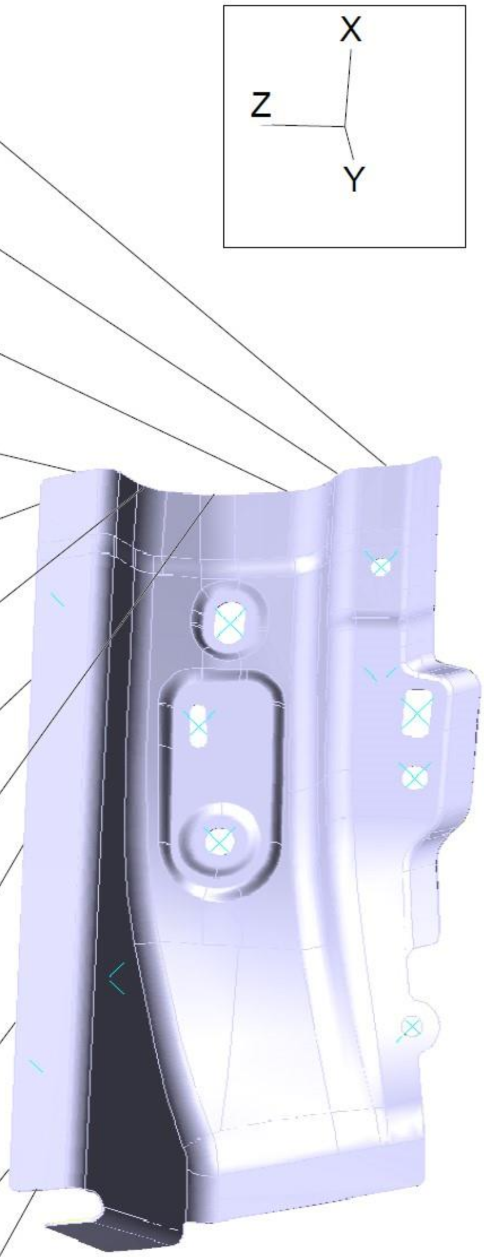

Fig. 6: Results of shape deviations measurements of irregularly shaped stamping using blank from strip steel DX54D after trimming (example for edges 24 to 35), off-size value that is over the border prescribed value 0.50 mm on the production drawing is marked by red colour

For the practice view, it was necessary to compare the springback size between the nominal shape that is determined in the part drawing and springback geometry of the stamping shape. For the resulting springback size evaluation the plane sections were selected in which the nominal geometry of the shape was compared with the geometry of springback stamping.

The deviations of stamping geometry shape were logically minimal for all considered strip steels in the section planes located near the RPS points in comparison with other deviation differences. The deviations of stamping geometry after springback reached maximum values in the plane surface of the flange and its opposite corners

(Fig. 8) because at these areas sufficient deformation of material did not occur.

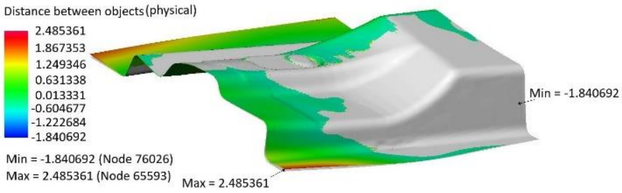

Fig. 8: Surface displacement of irregularly shaped stamping from nominal geometry of stamping shape (shown grey) in analysis "Signed Displacement" from nominal shape with chosen mesh strategy "Springback" for drawing tool parts and using blank from strip steel DX54D, situation before trimming

Comparison of the deviations presence frequency of stamping geometry after springback towards to nominal geometry of stamping and measured values on the 3D measuring device Wenzel are shown in Tab. 5. The results are within tolerances specified on the part drawing. Then there are also given deviations presence frequency in the lower zone of tolerance for steel strips DX54D, HC220P, HX220BD and HX220YD which is given for reduction of probability of scrap arising.

Table 5. Comparison of the deviations presence frequency in toleration and deviations presence frequency in the lower zone of tolerance for steel strips DX54D, HC220P, HX220BD, and HX220YD determined by simulations and measured values on the 3D measuring device Wenzel

Mark of steel	Mesh strategy „Springback"		Mesh strategy „Compensation"		Measured values on the 3D measuring device Wenzel	
	Deviations in tolerance (%)	Deviations in the lower zone of tolerance (%)	Deviations in tolerance (%)	Deviations in the lower zone of tolerance (%)	Deviations in tolerance (%)	Deviations in the lower zone of tolerance (%)
DX54D	88.90	63.60	91.24	60.10	83.33	66.67
HC220P	38.53	22.53	32.28	26.30	37.49	25.34
HX220BD	83.80	40.60	88.30	50.00	79.16	43.35
HX220YD	83.50	41.70	85.20	48.40	77.50	42.33

While using both mesh strategies the highest frequency of deviations in terms of springback that are located within the tolerance has the stamping from strip steel DX54D. On the contrary, the lowest frequency of deviations has the stamping made from strip steel HC220P. In the mesh strategy *"Compensation"*, the greatest frequency of deviations present in the lower zone of tolerance, has the stamping from strip steel HX220YD. The lowest frequency of deviations present in the lower zone of tolerance has the stamping made from strip steel HC220P.

When using both mesh strategies it was found by section planes that at all of the materials exist the deviations from the nominal geometry of stamping shape, especially in side walls of stamping, in transitional radius between wall and surface flange that springback size increases. The cross sections from opposite ends of the stamping were turning when using blanks from all strip steels which is the consequence of stress in the stamping. This tension causes torque arising in part side walls and in both flanges. The curvature of the transition edge occurs between the straight sides of the flange to the sloping wall on the stamping right side in the middle (Fig. 8). This phenomenon cause is the effect of bending moment in the plane perpendicular to the cross-section. Springback occurred as a consequence of different ratios towing on the edge and in the stamping middle side wall. This defect arises in combination with cross-section turning.

At edge No. 30 (see Fig. 6) in the direction of the y-axis the difference between actual and nominal shape after trimming is 0.61 mm, which is 0.11 mm above the allowed value of 0.50 mm. This problematic area of stamping corresponds with the result of the simulation in Fig. 8.

For evaluation and comparison of the drawability of real irregularly shaped stamping (see 1) the drawing process simulations and the springback size simulations in software PAM-STAMP 2G™ for strip steels DX54D, HC220P, HX220BD and HX220YD with mesh strategies *"Springback"* and *"Compensation"* for drawing tool parts were used. The critical areas of stamping wall thinning signalizing the risk of fractures were identified (Fig. 5) on real stamping because at irregularly shaped stampings these critical areas cannot be avoided. By local thickening of material in side walls and in transitional depression at the stamping the secondary wrinkling arises when using all evaluated strip steels. Differences among mesh strategies in the results of the analysis of wall thickness significantly manifested at strip steel DX54D in the analysis of thinning of the material over 25 % (see Tab. 4). In mesh strategy *"Springback"* the thinning above 25 % of blanks from given strip steels does not occur but in mesh strategy *"Compensation"* the material thinning over 25 % occurs strongly. For the solved stamping drawing processes simulation the limit value for the necessity of stamping design changes is 30 % thinning of walls which was not achieved when using any evaluated strip steel. Based on the forming limit diagram of solved stamping (see Fig. 4) can be stated that its geometry is convenient for safe drawing. When using the mesh strategy *"Compensation"* for drawing tool parts, more accurate results are achieved that credibly describe the drawing process simulation.

For all tested strip steels the differences between dimensional deviations of stamping after springback determined by simulations and dimensional deviations of stamping after springback measured at real stamping using RPS points were detected in the range of (2.77 ÷ 14.88) % for strategy *"Springback"* and range of (3.78 ÷ 14.34) % for strategy *"Compensation"*. The smallest difference between dimensional deviations of stamping after springback determined by simulations and dimensional deviations of stamping after springback measured at real stamping using RPS points was evaluated at strip steel DX54D which has lower yield strength compared with other strip steels.

5 CONCLUSIONS

At all evaluated strip steels DX54D, HC220P, HX220BD and HX220YD in springback process simulation of irregularly shaped stamping occurred increased the radius between side walls and stamping planar surfaces. The cause is the unequal distribution of stress and prospective stress gradient in the thickness of sheet metal. In terms of achieving the minimum size of springback after drawing irregularly shaped stamping, the use of strip steel HX220YD was evaluated as the most suitable. The results are slightly worse when using strip steel DX54D, strip steel HC220P is the least appropriate.

Critical areas identified by stamping drawing simulations were compared with the actual measurement set of stampings. Measurements of shape deviation areas and the stamping side wall locations were carried out at the measuring device using RPS points. By comparison with the real stamping, it was evaluated, that the critical areas, in which the unsatisfactory deviations from dimensions specified at production drawing occur in critical areas of wrinkling that correspond to areas identified by drawing process simulations. At irregularly shaped stampings these critical areas cannot be avoided but by a suitable chosen number of draw steps, it is possible to influence positively the final stamping dimensions accuracy.

The described procedure for analysing the amount of springback at individual points of the stamping after drawing and the method of measuring the actual dimensions of the stamping can be applied to any sheet metal stamping. The values obtained in this way allow the dimensions of the drawing tool to be tuned to achieve a condition where the shape deviations of the final stamping correspond to the prescribed tolerances on the part drawing.

At solved irregularly shaped stamping the complying with the tolerances specified at the part drawing is troublesome as a result of springback, so it is suitable to use after drawing an additional operation – calibration.

6 ACKNOWLEDGMENTS

This work was supported by the SP2023/020 research project.

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