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SPRINGBACK COMPENSATION IN COLD FORMING PROCESS FOR HIGH STRENGTH STEEL

KOMPENSACJA SPRĘŻYNOWANIA W PROCESIE FORMOWANIA STALI NA ZIMNO

Process of metal forming in automotive parts construction becomes more and more demanding due to tightened up tolerance and trials to realize very complex and in many cases unworkable design in mass production. Moreover it is required to cut and limit costs of die production and simultaneously keep high quality. Furthermore, construction elements are more often produced from materials which belong to High Strength Steel or Ultra High Strength Steel. Application of this kind of materials considerably reduces construction mass due to high durability. Nevertheless, it results in appearance of springback effect. Springback value depends mainly on used material as well as part geometry and in extreme cases deviation value from target part might reach in some areas high level. Reduction of implementation time, development of metal components and greater restrictions about designing and producing stamping tools generate extra costs. Designing of dies requires using of appropriate Finite Element Method software to make them more economic and less time-consuming. Therefore analysis of forming process alone is not enough to be taken into account. During the design process it is needed to include the die compensation to reach optimized blank sheet. Prediction of springback effect by tryout method and then correction of deviation is difficult arduous and painstaking. Virtual compensation methods make it possible to receive precise result in a short time. This way gives a huge economic advantage eliminating useless milling and allows to produce of die just in time. Optimization process can relate to individual operation as well as take into consideration intermediate stages in the final result, at the same time increasing the accuracy. Die compensation with software application was experimentally verified by prototype die. Quality requirements regarding products of sheet stamping process are very high due to the technologies of automatic assembly of formed components. Springback, as the main source of drawpieces inaccuracy, is the function of material data, shape of tools and process parameters. Therefore, springback deformation becomes critical problem especially for AHSS steel when the geometry is complex. Hence, it is necessary not only to find springback effect value but also include it during early stage of designing by tooling designers.

Keywords: Springback, Compensation, Optimization, Simulation analysis, Metal forming

Proces przeróbki metalu w produkcji elementów konstrukcji samochodów staje się coraz bardziej wymagający ze względu na zaostrzenie tolerancji oraz próby urzeczywistnienia bardzo złożonego kształtu w produkcji masowej. Do tego należy dodać ograniczenia i cięcia kosztów narzędzi formujących. Coraz częściej elementy konstrukcyjne wytwarzane są z materiałów należących do grupy Ultra High Strength Steel. Zastosowanie tego typu materiałów znacznie obniża masę konstrukcji ze względu na dużą wytrzymałość, jednak kosztem dużego wpływu na sprężynowanie. Wartość sprężynowania przede wszystkim zależy od zastosowanego materiału oraz geometrii części, a w skrajnych przypadkach odchyłka od nominału może wynosić lokalnie nawet kilkanaście milimetrów. Redukcja czasu realizacji i rozwój metalowych komponentów oraz coraz większe restrykcje dotyczące projektowania i produkowania narzędzi tłoczących generują dodatkowe koszty. Przewidywanie efektu sprężynowania metodą prób i błędów, a następnie korekcja dewiacji jest bardzo trudna oraz pracochłonna. Metody kompensacji numerycznej pozwalają otrzymać dokładny rezultat w stosunkowo krótkim czasie. Daje to dużą przewagę ekonomiczną, eliminując dodatkową obróbkę oraz pozwala na terminowe wykonanie narzędzia. Proces optymalizacji jest funkcją, która może odnosić się zarówno do poszczególnych operacji, jak i również uwzględniać etapy pośrednie w końcowym rezultacie, tym samym zwiększając dokładność. Wymogi jakościowe odnośnie produktów procesu tłoczenia blach są bardzo wysokie ze względu na technologie automatycznego montażu tłoczonych komponentów. Sprężynowanie, jako główne źródło niedokładności wytłoczek, jest funkcją danych materiałowych, kształtu narzędzi i parametrów procesu. Dlatego też, deformacja sprężynowania staje się krytycznym problemem, przede wszystkim dla stali UHSS przy złożonej geometrii części. Stąd też konieczne jest nie tylko znalezienie wielkości efektu sprężynowania, ale i jego uwzględnienie podczas wczesnego etapu projektowania przez projektantów narzędziowych

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1. Introduction

Forming processes are widely used during manufacturing of vehicles construction parts. Their main attribute is high efficiency, repeatability and first of all economy, simultaneously keeping the proper surface condition in mass production. Efforts are made to replace construction elements with aluminium alloy, magnesium alloy and composites. In 2002 constructions contained about 0.5% magnesium and 8.8% aluminium but in 2010 respectively 2% and 12% [17]. There are some trials of mass production of construction elements as integral composite parts. Moreover, their durability is similar to high mechanical parameters of Advanced High Strength Steel (AHSS).

Their main advantage is low mass, even 30% less than in the same elements made from conventional steel. However, the composite is not able to provide all properties that have stamp parts. It is caused by lack of repeatability with divergence even to 30%.

Technologies of composite materials are said to be transferred from construction of high-performance vehicles to automotive. However, the problem occurs concerning possibilities of servicing cars after crash. In fact, damage of composite material structure eliminates a capability of their repairing, especially it is not as easy as for steel elements.

Main qualitative expectations of customers are: exterior look, safety, comfort, high engine performance and low fuel consumption. Higher standards of comfort and safety cause continuous rise in vehicles weight [7]. Therefore, new solutions are still being searched in order to ensure optimal mass supporting structure and positive crash tests results. Creating some brand new steel grades with strong mechanical properties had a ground breaking contribution in steel researches. These materials are divided into groups according to ultimate strength values:

- conventional steel with High Strength Steel (HSS) $300<R_m<600$ MPa which continuously contains High Strength Low Alloy (HLSA), Bake-Hardenable (BH), Carbon-Manganese (CMn) and partially Dual Phase (DP);
- - Advanced High Strength Steel (AHSS) with $600<R_m<2000$ contain Dual Phase, Martensitic Steel (MS) and Transformation-Induced Plasticity (TRIP) [15]

The results of many researches done by joint international projects during latest decade are AHHS materials. They enable obtaining high endurance materials at the same time preserving good plasticity. Although these two parameters do not go hand in hand and the increase of one of them is at the expense of the other, some material groups have beneficial values of both.

These competitive properties and economic considerations are the main reasons that steel is dominant material in automotive. According to the forecast, for the next years the stake of HSS and AHSS materials in car's body is about 90%. These trends are about to meet the requirements regarding decrease of overall construction mass, simultaneously increasing the safety and decreasing fuel consumption [7].

Traditional methods of designing and production were mainly based on designers' experience. However, the effective method of stamping processes designing must use CAD/CAM

capabilities as well as join abilities of numerical analysis and the one based on optimization methods. Currently for the analysis of forming process as well as designing of forming tool, the Finite Element Method (FEM) software is widely used.

In automotive, the numerical analysis is used to explore and predict forming possibilities in practice, in order to avoid some drawpieces mistakes. The potential problems of stamping process during designing of the tool can be eliminated by virtual software rather than by a process of trial and error. The advanced and complex software enables fast and certain verification if the assumed method is correct, what gives an advantage over traditional methods of trials. The most up to date methods of designing, manufacturing and planning of production must be used to meet demands of the market. Planning is one of the most important stages of designing the tooling technology to shorten the time of manufacturing process start. For the process of sheet stamping this stage is not only extremely crucial but also difficult. It is not easy to predict the number and type of forming stages, the accuracy of springback effect and to take into account inhibitory factors such as: wrinkling, cracking [11, 4].

Since the second half of 1990s the intense research works were carried on regarding linking of designing surfaces and die stampings in parametric way. The first purpose was development of the parametric models using extra surface which strictly corresponds with the surfaces participating in the process. The next step was creating of general solution for various designs with the use of linking of known features. Dies software such as: METHOPLAN (iCapp, Zurich), Viking (Inpro, Berlin), DIEDESIGNER (Autoform, Zurich) was being developed which tended to design complex and parametric assemblies of bodywork construction. Designing in parametric way enforces linking of software supporting die stampings construction and FEA method in order to design a proper surface [5,6].

Generally, it is required to use parametric methods of car designing what enables fast modification and implementation of essential constructional changes.

More and more often the optimization of all parts geometry finds the application. They are produced in many forming processes, creating the assembly which is built by components manufactured in different ways. One of the examples is combination of part made by cold forming and the one made by hot forming. The entire assembly joined by binder must fulfil the assumptions made at the beginning of designing process. Therefore, the optimization corresponds with complex chain of forming stages rather than single operation.

The manufactured parts are very often made by AHSS steel, which are less deformable and show bigger tendency to springback effect than mild steel. Springback compensation by means of tooling geometry change is necessary to be situated in narrower tolerance intervals. The quality of stamped parts has greater and greater importance. It influences the assembling stage and the final quality of product. One of the factors affecting the quality of drawpiece is the shape-dimensional accuracy connected with material springback. Researches done during last years caused the constraint of tolerance range in constituent components as well as in assemblies. More and more often in order to obtain high geometry stiffness, there

are designed some elements. Their executing reaches limiting values of possibilities for mass production. In computers age, tool compensating is evaluated by application of an analysis based on FEM methods. The accuracy problem of springback modelling is treated in literature as highly complex. The main cause of such opinions was computers' limited design power forcing applying lower nodes amount and number of elements at high time increments and lower refinement level that lead to a large compute springback error. Limits of hardware computers opportunities vastly reduced application of capabilities of software numerical analysis till 2001. It caused low accuracy of elements with complex geometry with relation to thickness of parts and long calculating time. The progress of 64-bit system software version was a huge breakthrough that caused higher output of Central Processing Unit (CPU) and simultaneously reduced computing time. Numerical calculations of forming are reduced to describe a surface with elements that are based on nodes. The number of nodes is given to ensure good precision of calculation. A good way to determine size of elements is the functional dependence between the smallest radius and thickness of a sheet. Computation of springback requires huge accuracy. Therefore, there are used elements with small dimensions, little time increments and accurate material data in zones where some contact with a tool appears. A very important factor is using of proper elements during an analysis of forming process. Usually, FEM programmes dedicated for stamping use surface elements that have more developed counting algorithms and what is the most significant they reduce their time. Volume elements take into account 3D plasticity due to double contact. Application of TTS (Through Thickness Stress) elements is well-founded for flanging on account of process specification. Using of computer supporting designing and an analysis of stamping process tools helps to achieve a target in an advised way and most of all in attainable time. The analysis itself is not enough because of the necessity to take into account tool compensation.

Nowadays, compensation calculations are carried out in automatic way or at least semi-automatic with the use of FEM software (e.g. Pam Stamp, Autoform, Ls-Dyna, Outifo, Mashal). Development of compensation method for Pam-Stamp 2G software took place in 2002-2004. The accuracy and correctness of this method was affirmed for designing parts in years 2004-2005 for: Arcelor (B-pilar) and Renault (bodywork elements).

Pam-Stamp 2G software module is based on a method from 2005. In 2011, researches that were done on the progress of compensation methods leaded to enlargement of the basic optimization process tool. Cooperation between the ESI Group and the Atlas Tool company leaded to the verification of the experimental method. Carried out trials were done on a few parts, for example on a deep stamped A-pillar made from UHSS steel. In result, it was found that using the complex process optimization allows to obtain the compensation on minimal 90% level of compatibility with the part [1].

At present, it is possible to compensate the whole operation chain, which enables to take into account the springback effect on all process stages. It also gives an advantage in solving some problems with finding an accurate surface for cutting operation and matching the sheet to the tool during every individual operation. Skipping of the multi-operational compensation tool

requires taking into account unstressed surfaces on particular trimming stations, which is not quite right, so it surely contains some fault.

2. Compensation

The main idea to correct the die consists in application of classic springback compensation used in technological conditions which is extra overbending or sheet overpress during forming, in order to reduce the springback effect. For simple forming, the problem comes down to the additional sheet overbending. However, if the geometry is more complicated, it is not easy to predict the behaviour of material. Nonlinear behaviour during stamping process depends on a state of stress, a state of strain and on material deformation history. According to the material forming analysis containing springback, its description of tool loading changeability has a distinct effect on a final analysis. The definition of tool and blank sheet interaction determined as a contact friction of constitutive model is also used to model the used density of mesh for a charge and a tool.
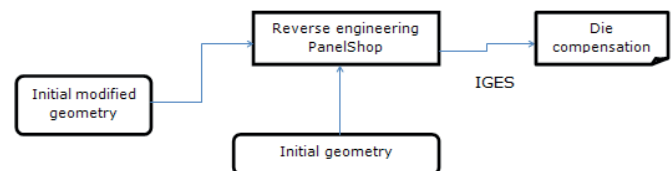

Fig. 1. Engineering process of modified parts' geometry creation

Development of compensation methods based on successive approximation methods with the possibility to define the measure direction and quality of compensated elements enables accurate finding of unstressed surface. The algorithm of the die correction, with the use of dislocation in elastic range, assumes iteration procedure of springback effect compensation.

Springbacks come out after lightening of the press parts by the strength or after release of the residual stresses during trimming operations. The great influence has also the run of forming process and planning of hardening process [16].

The important issue is springback value which can be calculated by formula:

$$\delta E = |\Delta_f - \Delta_t| \qquad (1)$$

The precision while forming can be expressed as:

$$\eta_{\delta\Delta} = \frac{|\Delta_f - \Delta_t|}{\Delta_f} \, 100\% \qquad (2)$$

Where δE- springback value, Δf- real compensation value, Δt- analyzed compensation value, $\eta\delta\Delta$- precision of compensation [2].

The main compensation targets are:
- identification of tooling geometry which adjusts the surface to minimize the distance between assumed geometry, in such way, that the initial tooling geometry will be modified (overbent),
- compensation should be studied in virtual, numerical way to reduce classic ways of modification to minimum (e.g.-

trial and errors method) or omit them totally:

- presentation of compensation range with the use of tool mesh,
- description of surface in CAD format (e.g. IGS),
- description of surface including the history of all surfaces during consecutive iterations,
- transformation of compensation result by the surface description:
- mesh transfer with the modified die surface,
- possible formats of transfer (Ansys, Asci, Ideas, Nastran).

It is possible to obtain CAD surface as a clean mesh based on reverse engineering (Fig.1) method but the most often it leads to the low surface quality.
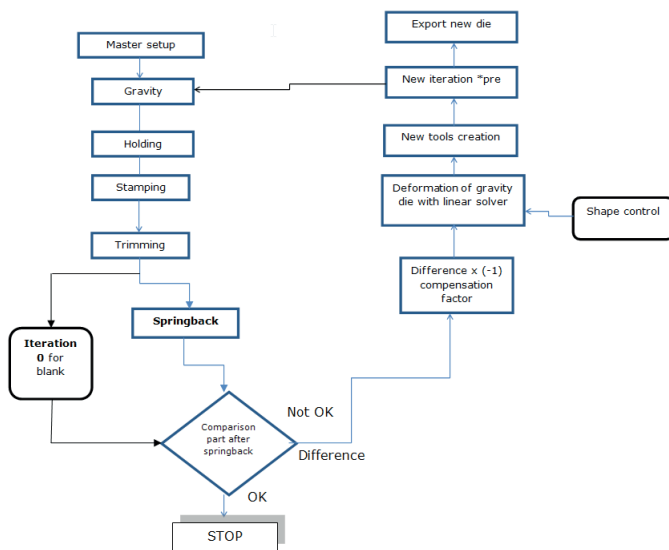
Fig. 2. Iteration analysis of compensation process

There are die and part compensation which are closely connected. However,, in industrial conditions the compensated surface of the tool is searched, which is necessary during the process of stamping die designing. It means the modification of tool surface geometry during designing of forming process and the necessity to optimize the effect. The algorithm of die correction assumes iteration procedure of springback effect compensation (Fig. 2),. It often happens that optimization can end up successfully on condition that entire forming process linked in correlation chain (forming, trimming, bending and separating operations) will be analyzed. The most often springback occurs after cutting and separating operations. The natural restriction to apply methods of die shape correction are drawpieces which have vertical walls because after correction we get tools of wall angles bigger than 90 deg, what requires special tools for shaping. Similar restrictions appear for die stampings which have a big area of flat surface [9].

FEM software enabling optimization of full process chain is not enough. It happens due to the fact that such programs do not generate surface in CAD but only as the collection of nodes. It is enough for theory but not in the industrial conditions.

Creation of the die stamping requires milling of each of its part. Therefore, in the next step it is necessary to convert the mesh in the form of different formats (e.g. Nastran, Ansys files) into more general CAD formats (e.g. IGS). The most

often transition between two softwares generates imprecisions in the form of non-tangency discontinuity and small surface smoothness. The die optimization requires the input data which include the original compensated mesh and CAD data of the die. Thanks to that, there are contained 2 codes of the net of heterogeneous CAD surface zone dislocation. It means, that every surface is tightened to the new shape which is not usually bigger than the same surface before the compensation (e.g. cylindrical surface will not be the cylindrical surface, flat surface will not be the flat surface etc.).

Obviously, NURBS surface model data basing on following increase of the surface flexibility in nodes will be conform to compensated elements. Therefore, the main loop for every surfaces is checking the accuracy, local nodes till the assumed tolerance will be reached everywhere besides surface definition. This process generates the path with maximum continuity determined by double tolerance. Searching the correct, cut surface we need to make a global dislocating area definition. We solve for the unknown vector valued parameters λ:

$$M(p) = \sum_{i=1}^{n} \lambda i \phi(\|p - pi\|) \qquad (3)$$

$M(p) = c_i v_i$ belongs to the set [1,n]: interpolate c_i z: $\phi(r) = r$ - harmonic radial basis function.
Where n is a number of movement vectors.

The adjustment of nodes to the 3D model of the part takes place so that the surface is stretched on the mesh. The process is implemented by PanelShop software (iCapp) [5].

The innovative compensation method that additionally contains compensating of trimming stations was taken into account in the process. A standard compensation method contains only the cutting process during a springback calculations but does not include compensating of shape of the trimming stations (changes of the trimming operations surfaces). The compensated surface of the trimming station should be geometrically fit between a nominal surface of the forming operation and the compensated surface of the same forming operation (Fig. 3). Mostly, when the springback compensation process was predicted, the surface of the trimming operation is the nominal surface or the compensated one. Using the compensated surface on the trimming and the forming stations increases an accuracy of the whole process. It allows for getting a better compensation result, even a few percent than the standard compensation process. If the compensation is not included on the trimming station it causes growing of the reference surface deviation. What is more, it also influence on stamped blank positioning errors that appear on trimming station because of the springback difference before and after the trimming process. Therefore, it is recommended to apply this method in order to enhance dimensional tolerance and surface quality. In some particular tools analysed by the authors occurred situations that the springback effect was eliminated by the standard compensation. However, positioning problem was so large that the blank sheet between stations distorted itself, which was visible at the finished element. As a result, it leaded to search a compensated surface that was usually separated between the operations, which reduced the effect of irregular positioning. Obviously, this situation ought to be predicted during designing the tool in order to avoid

extra costs related to rework the existing tool and time delays in delivering prototype elements.
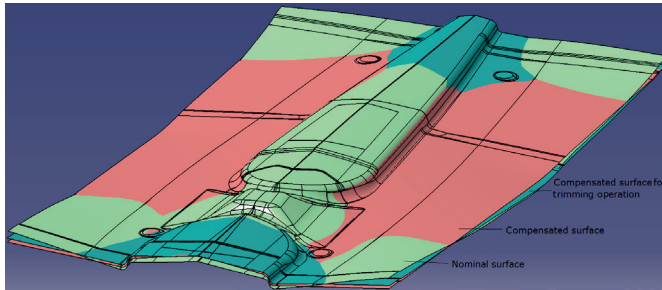

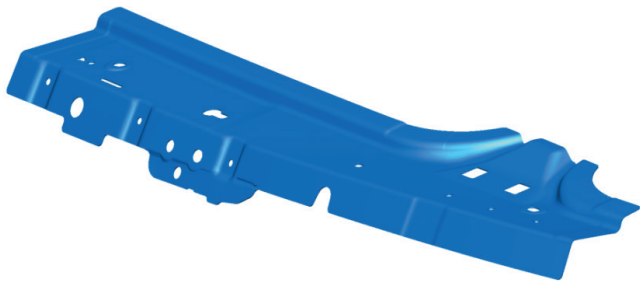Fig. 3. Comparison compensation surfaces to reference

Fig. 4. Analysed roof structure part

3. Numerical model

The subject of the work is analysis of the part shown in the pictures (Firg. 4). This part is an example of an element which causes some difficulties due to its geometry specification and an used material. During designing of the forming tool, many problems were encountered. They had an influence on quality of die stamping, such as: big springing, especially for local z axis. PAM-STAMP 2G software version 2011.1 was used to the computing. It enabled the numerical analysis of the forming process and the complex, full- chain optimization of the forming die OP-20 and cutting die OP-30 and OP-40. The numerical analysis FE made for material model Hill 48 explicit and implicit uses computing methods according to the advice given by the software suppliers with the aim to minimize the time of computing, simultaneously keeping the satisfactory accuracy of server calculation. The process of forming surface of the part during the deformation of the sheet joins two ways of loading by bending and tensile forces.

As the result, the complex state of stress is received which is not always easy for analytical notation as the reduced strength hypothesis. The material used in forming process has the nominal thickness 1.35 mm whereas the dimension of blank are 873 x 222 mm. For the sake of the simulation producing from the left and right hand part, the single blank sheet symmetry can be used, what has shortened the computing time. Springback was computed also taking into consideration the plane symmetry due to the cutting operation before the restraining of the tool. Use of the symmetry caused the necessity to include the boundary conditions. It means that six translations must be locked by the statically determined way.

The elements of triangle and quadrangle surface type of nonlinear stress distribution towards thickness were used. They are based on Belytschenko- Tsay model which relies on uniform, coherent and reduced integration (ESI 2011). The number of elements was optimized relatively to the computing time, so that the accuracy reflects the reality. Forming die OP-20 contains 698267 elements and 173554 nodes, whereas blank sheet initially contained 3569 elements and 924 nodes in such way that in the final stage of the process attained about 131245 elements and 33151 nodes.

4. Material model

Applied DP-800 material is steel that belongs to UHSS group, diphase, cold rolled. Steel structure is formed by the compound in die form of martensite precipitates on fine-grained ferrite warp. There also may appear small amounts of retained austenite. These steels are received by suitably leaded cooling after annealing from temperature range conforming coexisting of α and γ phases. The properties of this steel which is a kind of specific composite are the resultant of portion of hard and resistant martensite and ductile ferrite. There is also high initial yield point and ultimate strength which quickly decline during the plastic working. Hill 48 material using isotropic hardening curve was approved despite of the fact that software uses criterion of isotropic-kinematic consolidation hypothesis.

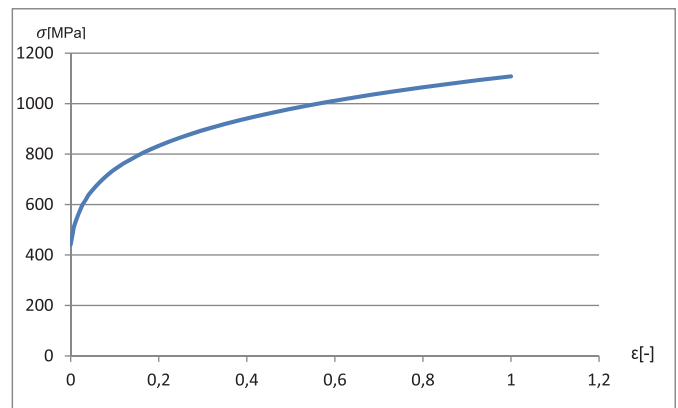Chosen material requires following basic parameters describing material.

Fig. 5. Hardening curve for DP-800 material

Young Modulus E=210GPa, Poisson coefficient υ=0.3; density ρ=7.8*10-6 g/cm³, rolling direction along shorter edge of blank sheet (local x axis) and blank thickness g_0=1.35 mm [10].

Normal anisotropy can be expressed by r_α in direction:

$$r_\alpha = \frac{\varepsilon_2}{\varepsilon_3} = \frac{\ln(\frac{b}{b_0})}{\ln(\frac{g}{g_0})} \quad (4)$$

Where: α - the direction of the sample; b – the width of the sample; g – the thickness of the sample; - accordingly initial values

Coefficient describing normal anisotropy r is regarded as the average value which can be determined from the formula:

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$$r = 0.25(r_0 + 2\, r_{45} + r_{90}) = 0.25(0.77 + 2*1.14 + 1.07) = 0{,}88 \qquad (5)$$

Hardening curve determined by static test of bumping for 0° direction after calculating stress value and actual strain (Fig. 5). Next, the curve was extrapolated in order to increase the range of actual strain [8]. To reach that, the Krupowsky formula was used:

$$\sigma_w = K\left(\varphi + \varphi_0\right)^n = 1161(\varphi + 0.00056)^{0.111} \qquad (6)$$

The hardening curve is not enough during forming analysis. Forming Limit Diagram (FLD) must be used additionally, in order to precisely verify the nodes which are critical in terms of maximal stress.

It is a diagram of steel drawability shown with the use of main straining. The curve can be determined by the Nakajima Test or by other experimental method. [3,12].

5. Numerical parameters

The blank sheet is treated by default as the middle layer without thickness. Contact between the die and blank was adopted as automatic. It means that solver adapts the type of contact depending on corresponding conditions and type of calculation, at the same time giving user the chance to verify the correctness of that choice anytime. In OP-20 and OP-50 the blank-holder was used in order to decrease the wrinkling (Fig.6, 7, 12).
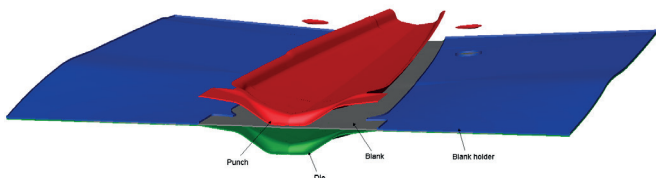

Fig. 6. FE model in OP-20 with die, blank-holder, punch surface

Defined forces equal relatively 300 kN (OP-20) and 700 kN (OP-50). The speed of blank-holder has been defined as 2 m/s, while the speed of forming as VBC (Velocity Balanced Curve) as maximal value of 5 m/s. Modeling of contact that is based on the method of penalty friction coefficient between cooperating surfaces is described as Coulomb bilinear model. It uses static and dynamic coefficient friction or function depending on variable of the other parameter e.g. stamping velocity, pressure force etc. The friction model as Coulomb's coefficient has been defined as constant value $\mu = 0.12$ (ESI 2011). Level of refinement of the mesh is based on criterion of minimal radius value r=2, which enforced refinement degree on level 6 and the minimum element value is 0,64 mm.
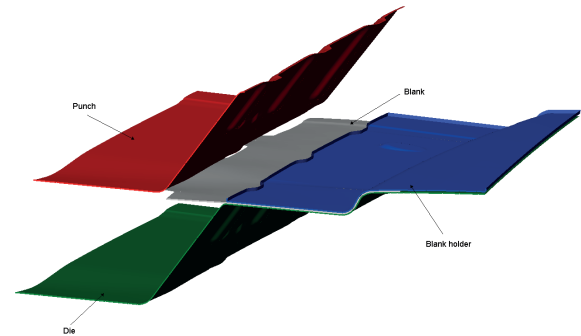

Fig. 7. FE model in OP-50 with die, blank-holder, punch surface

6. Springback prediction

In designing of cold forming tools springback should be taken into account. In addition to the internal stresses which arise as a result of bending, there is a residual stress distribution in cross-section of bent material. This residual stress distribution depends on the extent to which the material underwent plastic deformation. Even though the springback effect is sometimes more or less visible depending on sort of material, it is a result of bending the material. For parts with no complex geometry, the analytic methods of solution are advisable in order to estimate the size in a quick way. However, complex constructions with complicated shapes require numerical solution of the issue.

The accuracy of predicting of the springback also depends on the influence of coefficients which are responsible for forming analysis quality. Initially, maximum springback value was assumed as about 8 mm in the direction of local z axis. [3,13,14].

7. Finite element analysis

The conducted analysis of stress state accepts the level below 20% (customer requirements) of thinning, although initially there was found a big tendency of material superposition and the area of cracking propagation.

The change of geometry of OP-20 clamp surface and optimization of slang flanging method enabled to adjust the most proper process parameters.
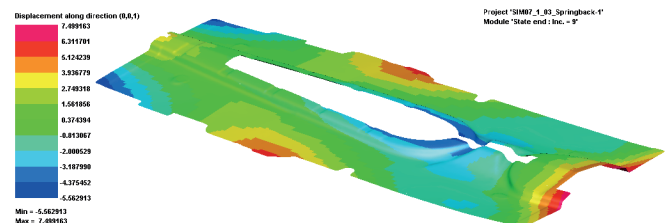

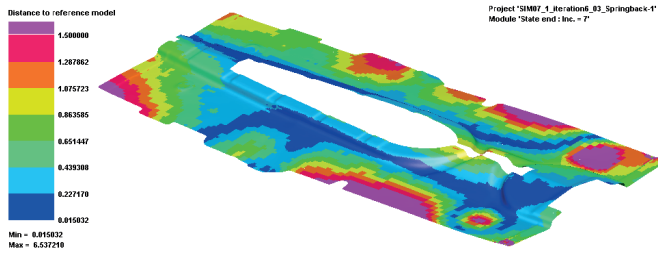Fig. 8. Springback deviation computed by FEM

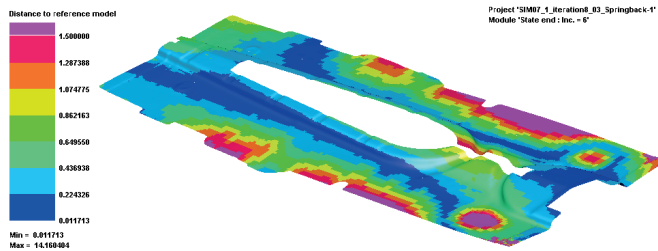Fig. 9. Distance to reference part after compensation without full chain

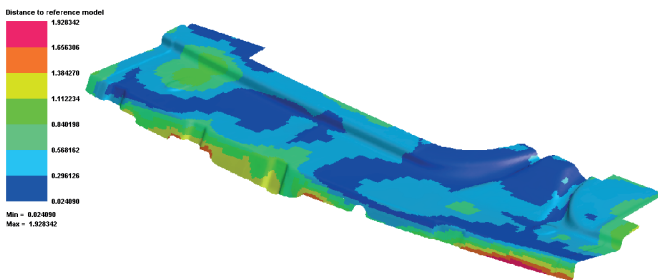Fig. 10. Distance to reference part after compensation with full chain

Fig. 11. Distance to reference part after OP-50 compensation with multi compensation
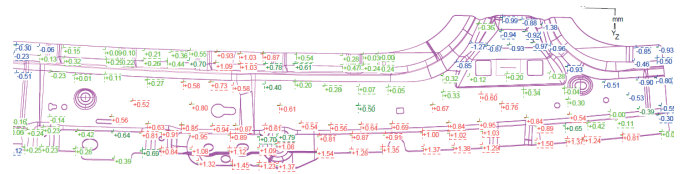

Fig. 12. Measured finish part with multi compensation by Coordinate Measuring Machine
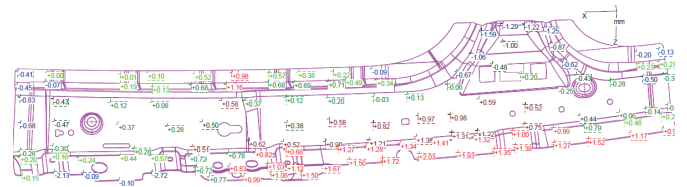
Fig. 13. Measured finish part without multi compensation by Coordinate Measuring Machine

8. Experimental verification

As it was numerically and experimentally proved, springback values reached the assumed level of about 8 mm for OP-20 (Fig. 8). The numerical analysis showed that the initial tool compensation without full chain compensation brought unsatisfactory result. The deviation value after compensating is above 2 mm, which vastly exceeded complex tolerance range. It is caused by optimizing only of OP-20 (forming) without taking into account OP-30 and OP-40 (cutting). During the trimming operation little deformation of an unstressed part occurred, which resulted in parts which could not meet the requirements of imposed tolerance +/- 1.25 mm. However, the application of the complex springback compensation enabled obtaining good parts which reached the tolerance required by the customer (Fig 9,10,11). It must be emphasized that some parts' zones are less important and may fit into general tolerance which is usually wider than for mating zones and amounts +/- 1.5 mm (Fig 11,12). Sometimes, bigger springback tolerance is also allowed in the spot of next calibrating operation and in that way it is used in the presented part. The zone with the deepest overpress is calibration in another OP-60 operation and therefore, compensation with lower tolerance is acceptable.

9. Summary

New materials such as UHSS give large structural potentials but unfortunately it requires using new technologies of the rework process of these materials. More and more intensive economic competition and increase of expectations of the final product force the increased efficient of a stamping department. Quality expectations of customers refer mostly to: appearance, security, comfort and low fuel consumption. It is related to visible elements for example outer element coverage, pillars that has also esthetic function which cannot accept any geometric deviations. Using curvilinear surfaces on components is meant to get smooth reflections so the formed surface does not contain surface defects. The forming process of materials with high mechanical parameters requires containing the complex compensation because such materials are highly prone to springback effect which is not always easy to eliminate. In regard of tightening geometric tolerance requirements, compensation of springback effect should meet the high customer expectations. Therefore, improved methods of reducing the springback are searched. They effectively eliminate die stamping errors. Influence on springback effect:
- variable coefficients such as: mechanical material properties, friction factor, blank geometry, precision of the elements;
- geometry of the tool (matrix radiuses etc.);
- parameters of the process (velocity, feed force etc,).

First of all, the most important is accuracy of simulation which allows for exact data concerning material, boundary conditions and process parameters. The material model is so important that it should take into account material data of the specific supplier already during springback calculation. If the exact value and type of element is allowed for, it guarantees keeping necessary accuracy and saving time. Defining of tool correction range influences calculation time so that taking into consideration only partial correction may be enough. It is also required to build the correct surface from nodes of defined coordinates to obtain uniform CAD surface of the tool. Compensation is determined so much by springback calculation

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accuracy that if they are not exact, then in the practice it will make it impossible to achieve the required result.

The breakthrough of compensation quality has occurred recently with the use of multi-operation compensation. It enabled the better simulation of reality by correction of individual tooling stations, what increased the precision of computation.

Reached compensated surfaces of forming and cutting operations at the stage of designing enable time saving and most of all reduce costs connected with the trial and error method. This kind of parts with such a complex geometry and material specification requires approximately a few months of hard work in order to reach the assumed geometry that is contained in the tolerance range. Drawpieces' defects such as cracking and excessive folding are easy to predict and eliminate, however the springback effect without virtual environment often remains problematic.

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